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Reduced Disposal Area Performance Utilizing Secondary-treated Effluent in Profile-limiting Soils

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Reduced Disposal Area Performance Utilizing Secondary-treated Effluent in Profile-limiting Soils

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by

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Abstract

Onsite wastewater systems dispose of primary treated effluent by utilizing the soil for final recycling and renovation of wastewater into the environment. Soil and site limitations have become a challenge to design a wastewater system and dispose of onsite wastewater using a conventional pipe and gravel design. Using secondary-treated effluent from an advanced treatment unit applied to a reduced disposal area offers an additional alternative when developing an onsite wastewater system. The objective of this study was to determine the feasibility of hydraulically loading limiting soils with secondary-treated effluent in a reduced disposal area. A reduced disposal area was constructed at six existing residences within the same subdivision that had shallow redoximorphic features that precluded using a conventional pipe and gravel wastewater design. Each residence had an existing advanced treatment unit with a surface discharge of secondary-treated effluent. Flows were diverted from the overland flow discharge to the reduced disposal area. Wastewater flows were recorded at regular intervals, along with ponding depths in the disposal area and fluctuations in the seasonal water table over a 12-month period (March 2017 to March 2018). The disposal areas were hydraulically loaded at 2 to 3.8 times the rate recommended for secondary-treated effluent. Wastewater effluent was sampled throughout the study and resulted in a mean of < 8.5 mg L^{-1} total suspended solids, < 5.3 mg L^{-1} biochemical oxygen demand, and > 6.3 mg L^{-1} dissolved oxygen, all of which met or exceeded the minimum water quality criteria for surface discharges of secondary-treated effluent. Three of the six sites showed ponding depths between 0 and 4 cm in the trenches during the study period. The remaining three sites showed ponding between 0 and 35 cm in the trenches during the study period. Based on the results of this study, a reduced disposal area utilizing secondary-treated effluent appears a feasible option to surface discharging.

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Dedication

This thesis is dedicated to my family, friends and employees who supported and encouraged me throughout this part of my academic career.

Table of Contents

List of Tables

Chapter 2

List of Figures

Chapter 2

Introduction

Introduction

Managing household wastewater (i.e., effluent) by onsite disposal is critical to keeping rural areas and water sources free from disease and unsanitary living conditions. According to the 2017 rural profile of Arkansas, 42% of the Arkansas population is classified as rural (Miller, 2017). Consequently, rural dwellings in Arkansas that are not connected to a public sewer system must utilize an onsite wastewater system that relies on the soil to renovate household wastewater before the water is returned to the natural hydrologic cycle.

In 1977, the Arkansas General Assembly passed the Sewage Disposal Act 402. Act 402 defined the guidelines for handling domestic waste. Following Act 402 the Arkansas Department of Health adopted Rules and Regulations regarding onsite wastewater disposal (ASBH, 2014). The Rules and Regulations are still referenced today and revised periodically, as necessary, with improved methods and technologies. As Arkansans continue to move into rural, undeveloped areas, the rural sites considered for development have become more challenging for design and installation of onsite wastewater systems due to limiting soils (i.e., shallow depth to bedrock, a shallow seasonal water table, or > 35% clay textures) or a limited disposal area on the property (ASBH, 2014). If a rural site is considered for development and the soils do not meet the minimum requirements established in the Rules and Regulations, an advanced treatment unit with surface discharge of secondary-treated effluent may be proposed. Advanced treatment units provide secondary-treated effluent that allows for surface discharge. However, an advanced treatment unit requires a minimum lot size of 1.2-hectares (ha), minimum surface discharge setbacks, and a National Pollutant Discharge Elimination System (NPDES) permit issued by the Arkansas Department of Environmental Quality (ADEQ). The investment in minimum area, the administrative requirements to maintain an NPDES permit, and the environmental concerns of overland-flow-discharging secondary-treated effluent all place a burden on the homeowner who must utilize an advanced treatment unit to develop a rural property because no alternative exists.

Currently, there are no data to provide any guidance for renovating secondary-treated effluent in Arkansas soils that do not meet minimum soil loading rate standards defined in the Arkansas Rules and Regulations for onsite wastewater disposal (ASBH, 2014). Therefore, the focus of this study is to investigate the impact of hydraulically loading secondary-treated effluent into soils that are limiting or have a limited disposal area. Exploring an alternative method for managing secondary-treated effluent disposal may reduce the need for NPDES surface-discharge permits, safely disperse secondary-treated effluent back into the hydrologic cycle, and provide development options as homeowners continue to move into rural areas that require an onsite wastewater system.

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Chapter 1

Literature Review

History

Our ability to live in Arkansas free from infectious diseases and in safe, sanitary conditions can be directly tied to how the wastewater generated by homes, businesses, and industry is properly managed and disposed. Arkansans recognized the public health concerns caused by unsanitary conditions from inadequate disposal of wastewater in 1913 with Act 96, which created a permanent Arkansas Board of Health (ABH, 1913). Additionally, in 1953, the Bureau of Sanitary Engineering passed bulletin No. 9, which further defined how to manage onsite wastewater systems (ASBH, 1954). Today, after several revisions, Arkansas' General Sanitation Rules and Regulations (ASBH, 2014) provide guidance on responsibly disposing of wastewater generated by homes, businesses, and industries in Arkansas.

Arkansas is considered a rural state. Densely populated areas manage wastewater demands with centralized collection, treatment, disinfection, and discharge under an NPDES permit. The remaining population of Arkansas, not connected to a centralized wastewater system, manage their wastewater demands with onsite wastewater systems. A conventional onsite wastewater system is typically installed underground and consists of a septic tank and a disposal field (OWRD, 2002). The septic tank holds and digests the solids and allows for oils and grease to separate before discharging the effluent generated by the user into a soil disposal field. The soil disposal field is an efficient method to safely renovate and recycle wastewater back into the environment. Harmful pathogens, nutrients, such as nitrogen and phosphorus, as well as other contaminants in the wastewater are degraded or bound in the soil profile (OWRD, 2002). Additional methods of managing the disposal of wastewater from an onsite wastewater system may utilize pumps or raised disposal fields. If the soil is considered too limiting for a conventional wastewater system, an advanced treatment unit may be considered with drip dispersal or an overland-flow surface discharge.

Onsite Wastewater Systems in Arkansas Quantified

According to the Office of Wastewater Management (NSCEP, 2008), 26.1 million households (20%) of the population utilize an onsite wastewater system in the United States. Arkansas' 1990 census data (USCB, 1990) reported 399,479 of households (39.9%) utilize an onsite wastewater system. The United States Census Bureau quick facts database (USCB, 2018) estimated 546,674 households used an onsite wastewater system in Arkansas. Based on an estimated 946 L d^{-1} wastewater flow per household, an estimated 517,153,604 L d^{-1} of wastewater are being returned into the environment in Arkansas each day.

Renovation of Wastewater and the Soil

Each day, wastewater from rural Arkansas homes and businesses is discharged into the soil where the effluent is renovated by filtering through the soil and recycled back into the environment using conventional onsite wastewater systems. The daily discharge of wastewater into the soil over time, with little evidence of contaminants or unsanitary conditions, shows how efficient the soil can be in renovating wastewater. However, as Arkansans continue to develop more rural areas that require an onsite wastewater system, locating suitable soil to safely renovate wastewater has become a challenge.

Arkansas Design Criteria for an Onsite Wastewater System

The onsite wastewater system design criteria in Arkansas is unique to the individual site being considered for development. Several factors must be considered in the design of an onsite wastewater system: home occupancy, estimated flow, soil suitability, and site limitations. The wastewater flow is based on the number of bedrooms in the home or maximum occupancy of the building (ASBH, 2014). The in-situ field observation of the soil characteristics is referred to as soil morphology. Soil morphology collectively refers to the characteristics of the soil profile and is determined by a scientific technique of documenting the properties of the soil profile in-situ by observing and recording characteristics various horizons. Common characteristics observed in-situ as related to an onsite wastewater system disposal are the soil structure, soil texture, depth to bedrock, soil matrix color, any redoximorphic features caused by reduction and oxidation, evidence of translocated material, or any other unique characteristic that may impact the soil's ability to transmit water.

Arkansas uses the redoximorphic features and soil texture in the soil profile observed to derive an acceptable effluent loading rate. Redoximorphic features indicate a seasonal water table is likely present during wet periods of the year. Seasonal water tables restrict the efficiency of a disposal field during wet periods. Additionally, site limitations, such as surface contours, surface drainage, adequate room for a disposal area, and adequate room for a secondary disposal area, are all considered when determining the suitability of a site for an onsite wastewater system.

Arkansas Soil Limitations

The soil is a major component of a conventional onsite wastewater system. Arkansas' soils vary in formation from weathered residuum, depositional alluvium and colluvium, to windblown eolian material. Soils formed from weathered residuum may have limitations due to clay content > 35% in the upper 120 cm of the soil profile. Another limitation in regards to weathered residuum is the development of a restrictive layer referred to as fragipan. Fragipans may exist in the upper 120 cm of soil profile and can restrict water movement due to increased bulk density that is often characteristic of a fragipan. In addition, a soil profile with < 45 cm of soil between the bottom of proposed disposal trench and bedrock with redoximorphic features above the bedrock, or a soil profile with < 60 cm of soil between the bottom of proposed disposal trench and bedrock without redoximorphic features above the bedrock, is considered restrictive for use as a conventional onsite wastewater system. Alluvial soils, which are created by flooding events, deposit soil particles in layers depending on the time span of the depositional event. The layers deposited may have very different textural properties. A layer of soil with clay > 35% within the upper 120 cm may restrict water movement and is considered a limitation. Therefore, soil profiles with clay percentages > 35%, with a fragipan, or that have a shallow depth to bedrock make designing a conventional wastewater system a challenge.

Arkansas Seasonal Water Table Definitions

In Arkansas, large clay percentages, fragipans, shallow depth to bedrock, and seasonal water table fluctuations during wet periods are considered restrictive when designing an onsite wastewater system. Seasonal water tables are recognized by evidence of reduction and oxidation within the soil profile. Reduction and oxidation (redoximorphic) criteria are defined in the

Arkansas Rules and Regulations and are used to denote three limiting seasonal water tables: i) the brief seasonal water table, with estimated duration of saturation for 6 days, ii) the moderate seasonal water table, with estimated duration of saturation for 18 days, and iii) the long seasonal water table, with estimated duration of saturation for 36 days (ASBH, 2014). Any seasonal water tables observed in the soil profile must be considered in the design of an onsite wastewater system.

In horizons with similar color patterns on ped surfaces and ped interiors and horizons without peds, the brief seasonal water table depth is defined as the soil horizon with concentrations or depletions with chroma ≥ 3, not greater than 20% chroma of 3, or iron (Fe) or manganese (Mn) nodules or concretions that are ≥ 2 mm in diameter (ASBH, 2014). The brief seasonal water table is the only seasonal water table that can be diverted with an upslope interceptor drain. An interceptor drain is a trench installed upgrade from the disposal area to divert seasonal soil and groundwater away from the disposal area. The moderate seasonal water table depth is defined as the soil horizon with a chroma 3 in > 20% of the soil matrix, or a chroma ≤ 2 in < 50% of the soil matrix, or a soil texture with > 35%, but < 50% clay (ASBH, 2014). The long seasonal water table depth is defined as a soil horizon with a chroma ≤ 2 in > 50% of the soil matrix, or a soil texture with > 50% clay (ASBH, 2014).

For design purposes, if both a brief and moderate seasonal water table are noted in the soil profile, an adjusted moderate seasonal water table must be calculated. The adjusted moderate seasonal water table is derived by subtracting the difference between the brief and moderate seasonal water table depths, dividing the difference by three, and subtracting the result from the existing moderate seasonal water table depth. Consequently, the result of this adjustment is referred to in the design specifications as the adjusted moderate seasonal water table. If a long seasonal water table is noted in the soil profile, the long season water table is adjusted by subtracting the long seasonal water table depth from the adjusted moderate seasonal water table depth, dividing the difference by two, and subtracting the result from the existing long seasonal water table depth. Consequently, the result of this adjustment is referred to in the design specifications as the adjusted long seasonal water table.

The brief, adjusted moderate, and adjusted long seasonal water table depths each have an assigned loading rate (ASBH, 2014). The most limiting loading rate is used to size the disposal field for the onsite wastewater system. If the brief seasonal water table depth is < 33 cm (13 inches), or the adjusted moderate seasonal water table depth is < 46 cm (18 inches), or the adjusted long seasonal water table depth is < 53 cm (21 inches), the disposal site is considered limiting and not feasible for a conventional wastewater system.

Primary-treated Effluent

In a conventional onsite wastewater system, the septic tank provides primary treatment of effluent by allowing the solids in the wastewater to settle, which is referred to as sludge. The grease and floatable solids rise to the top and are referred to as scum. The separation and accumulation of sludge and scum inside the septic tank is considered primary treatment. Primary treatment with a septic tank is a simple process for removing undesirable material from the wastewater stream before the effluent enters the soil disposal area. The septic tank reduces the strength of the wastewater by 45% from the inflow to the outflow (Bounds, 1997). In Arkansas, the strength of the outflow effluent must have a waste strength at or below a biochemical oxygen demand (BOD) of less than 300 mg L^{-1}, total suspended solids (TSS) of less than 300 mg L^{-1} and fats, oils, and grease (FOG) of less than 25 mg L^{-1} (ASBH, 2014). Primary-treated effluent is not considered safe to overland-flow discharge.

Secondary-treated Effluent

Secondary treatment encompasses any additional process after the septic tank that improves the wastewater quality. In a conventional onsite wastewater system, the soil disposal area is considered secondary treatment. The soil disposal area captures and clarifies the effluent from the septic tank by removing nutrients, pathogens, and remaining suspended solids (OWRD, 2002). The soil disposal area is the most efficient and cost-effective method to dispose of wastewater. However, if the soil disposal area does not meet minimum soil suitability criteria or the area for disposal is too small to accommodate the flow and accepted hydraulic loading rate, an advanced treatment unit may be an acceptable alternative. An advanced treatment unit is designed to reduce pathogens and suspended solids to an environmentally acceptable level before discharging the wastewater to an overland-flow point. An advanced treatment unit consists of a trash tank followed by an aeration chamber and final treatment through an ultraviolet light and post aeration. An advantage of the advanced treatment unit is that the advanced treatment unit may provide an option to developing a property with soils that are limiting. Disadvantages to utilizing an advanced treatment unit are the additional permitting expenses, on-going maintenance, and regulatory requirements to remain in compliance regarding an overland-flow discharge.

Challenges with an Advanced Treatment Unit and Overland-flow Discharges

The first challenge to overcome is that the infrastructure for an advanced treatment unit is more expensive than a conventional onsite wastewater system due to the processes required to balance food/substrate, time, and oxygen to produce an effluent quality safe enough to overland-flow discharge. Another requirement to own an advanced treatment unit is that, in Arkansas, a licensed, Class II wastewater operator is required to operate an advanced treatment unit. The Class II wastewater operator reviews and adjusts, if necessary, the advanced treatment unit once every three months. The availability and expense of a Class II wastewater operator can become a challenge for a homeowner. In addition, secondary-treated effluent from an advanced treatment unit that discharges to an overland-flow point at the surface is regulated by the Arkansas Department of Environmental Quality (ADEQ). The general or individual permit issued by ADEQ to an owner to allow an overland-flow discharge requires quarterly assessment reporting and semi-annual sampling and reporting of wastewater quality. The regulatory burden can be another challenge and expense to secondary-treated effluent and overland-flow discharges. Furthermore, the design requirements for an overland-flow discharge specify defined setbacks from property boundaries, neighbors, and the proposed home or structure in relation to the overland-flow point. Consequently, meeting the setbacks may place the overland-flow discharge point in a flat area with no path for the wastewater to flow, where surface ponding may occur and can create an environmental concern in the homeowner’s yard.

Relevant and Recent Research

Studies in the United States regarding wastewater systems utilizing an advanced treatment unit with shallow or reduced disposal areas are rare. However, the following studies utilized secondary-treated effluent and dispersed the water in a shallow or reduced disposal trench. In an unpublished study monitored by the Arkansas Department of Health, two separate failing conventional systems in Greenbrier, Arkansas were replaced with an advanced treatment unit and gravel disposal trenches 30-cm deep with 20-cm of gravel and a 10-cm layer of natural soil. The soil profile was mapped as Leadvale (fine-silty, siliceous, semiactive, thermic Typic Fragiudults) with silt loam to 55 cm including a fragipan at 55 cm and silty clay loam below. Secondary-treated effluent was dispersed by low-pressure distribution lateral lines and time-dosed. The modified onsite wastewater systems continue to function today, which alleviated the prior failure and any environmental concerns. In addition, Sievers (1998) studied secondary-treated water from an intermittent sand filter and a shallow disposal area on a single residence in Boone County, Missouri. The data gathered and results showed that secondary-treated effluent from an intermittent sand filter applied to a shallow reduced disposal area was feasible. The soil profile was mapped as Menfro (fine-silty, mixed, superactive, mesic Typic Hapludalfs) with silt loam to 28 cm and silty clay loam below. Ball (1998) conducted a study where an intermittent sand filter discharged secondary-treated effluent into a 125-cm deep, 30-cm wide, and 13-m long disposal trench receiving 2270 L d^{-1} for five years with no signs of ponding at the surface. The soil profile was noted as 71 cm of silt loam with a claypan below and a seasonal water table at 45 cm.

Tyler (2001) defined secondary-treated effluent loading rates based on organic loading of < 30 mg L^{-1} of BOD. Wastewater with low BOD levels was hypothesized to reduce pore clogging at the trench-soil interface. With the reduced bio-mat formation, soils could be hydraulically loaded with secondary-treated effluent at a rate greater than primary-treated effluent.

The disposal area required for primary-treated effluent is calculated by the flow, the hydraulic loading rate, and suitable area available. In some instances, the disposal area required by the flow and hydraulic loading rate is not adequate. The Washington State Department of Health studied the feasibility of a reduced disposal area utilizing secondary-treated effluent (WSDH, 2003). A reduced disposal area was deemed acceptable as a disposal method with secondary-treated effluent with recommendations of regular maintenance and primary and secondary sites being clearly defined and protected in case of future need.

Alternative Solutions to Secondary-treated Effluent and Surface Discharges

Current Arkansas Rules and Regulations allow drip disposal as an acceptable method to disperse secondary-treated effluent in soils that meet minimum soil suitability requirements (ASBH, 2010). Drip dispersal areas are generally 30 to 40% smaller than a conventional disposal area with similar soil characteristics. Drip dispersal is a proven technology and an acceptable alternative to an overland-flow discharge if the soil is suitable (OEPA, 2008). However, drip dispersal requires secondary-treated effluent and specific equipment to automatically or continuously flush the drip-dispersal tubing. Drip dispersal also requires specialized equipment, such as a plow, trencher, or vibratory blade, to install drip-dispersal tubing into the upper 25 cm of the soil profile. Furthermore, an additional license issued by the Arkansas Department of Health is required to install drip-disposal tubing. The additional infrastructure, additional license, and specialized equipment can make drip disposal a challenge for an entry-level wastewater system installer.

Justification

In Arkansas, there is only one option when the soil is too limiting for a conventional wastewater system or drip dispersal: an advanced treatment unit with an overland-flow, surface discharge. However, some soils that are too limiting for a conventional wastewater system may be adequate when utilizing secondary-treated effluent and shallow or reduced disposal areas. Exploring potential alternatives to overland-flow discharges will reduce the regulatory burden on homeowners. Furthermore, minimizing or eliminating overland-flow discharges is considered environmentally responsible by decreasing potential nutrient input into the receiving waters of Arkansas.

Goal, Objective, and Hypotheses

The overall goal of this research study was to investigate an alternative onsite wastewater system to the conventional pipe-and-gravel system for homeowner's with soil limitations. Therefore, the objective of this field study was to determine the feasibility of hydraulically loading limiting soils with secondary-treated effluent in a reduced disposal area. It was hypothesized that limiting soils hydraulically loaded at twice the loading rate established by Tyler (2001) with secondary-treated effluent will not exceed a ponding depth of 27 cm for a consecutive period greater than 14 days in any disposal trench. It was also hypothesized that the performance of a shallow-drainfield or reduced-disposal-field-area approach will differ over time, specifically between wet and dry seasons.

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Chapter 2

Reduced Disposal Area Performance Utilizing Secondary-treated Effluent in Profile-limiting Soils

Abstract

Onsite wastewater systems dispose of primary treated effluent by utilizing the soil for final recycling and renovation of wastewater into the environment. Soil and site limitations have become a challenge to design a wastewater system and dispose of onsite wastewater using a conventional pipe and gravel design. Using secondary-treated effluent from an advanced treatment unit applied to a reduced disposal area offers an additional alternative when developing an onsite wastewater system. The objective of this study was to determine the feasibility of hydraulically loading limiting soils with secondary-treated effluent in a reduced disposal area. A reduced disposal area was constructed at six existing residences within the same subdivision that had shallow redoximorphic features that precluded using a conventional pipe and gravel wastewater design. Each residence had an existing advanced treatment unit with a surface discharge of secondary-treated effluent. Flows were diverted from the surface discharge to the reduced disposal area. Wastewater flows were recorded at regular intervals, along with ponding depths in the disposal area and fluctuations in the seasonal water table over a 12-month period (March 2017 to March 2018). The disposal areas were hydraulically loaded at 2 to 3.8 times the rate recommended for secondary-treated effluent. Wastewater effluent was sampled throughout the study and resulted in a mean of < 8.5 mg L^{-1} total suspended solids, < 5.3 mg L^{-1} biochemical oxygen demand, and > 6.3 mg L^{-1} dissolved oxygen, all of which met or exceeded the minimum water quality criteria for surface discharges of secondary-treated effluent. Three of the six sites showed ponding depths between 0 and 4 cm in the trenches during the study period. The remaining three sites showed ponding between 0 and 35 cm in the trenches during the study period. Based on the results of this study, a reduced disposal area utilizing secondary-treated effluent appears a feasible option to surface discharging.

Introduction

Managing household wastewater (i.e., effluent) by onsite disposal is critical to keeping rural areas and water sources free from disease and unsanitary living conditions. According to the 2017 Rural Profile of Arkansas, 42% of the Arkansas population is classified as rural (Miller, 2017). Consequently, rural dwellings in Arkansas that are not connected to a public sewer system must utilize an onsite wastewater system that relies on the soil to renovate household wastewater before the effluent is returned to the hydrologic cycle.

In 1977, the Arkansas General Assembly passed the Sewage Disposal Act 402. Act 402 defined the guidelines for handling domestic waste. Following Act 402, the Arkansas Department of Health adopted Rules and Regulations regarding onsite wastewater disposal (ASBH, 2014). The Rules and Regulations are referenced today and revised periodically with improved methods and technologies. Each day, wastewater from rural Arkansas homes and businesses is discharged into the soil where the effluent is renovated by filtering through the soil and recycled back into the environment using conventional onsite wastewater systems. The soil captures and clarifies the effluent from a wastewater system by removing nutrients, pathogens, and remaining suspended solids (OWRD, 2002). A soil disposal area is the most efficient and cost-effective method to dispose of wastewater. The daily discharge of wastewater into the soil over time, with little evidence of contaminants or unsanitary conditions, shows how efficient the soil can be in renovating wastewater. However, as Arkansans continue to develop more rural areas that require an onsite wastewater system, locating suitable soil to safely renovate wastewater has become a challenge due to limiting soils (i.e., shallow depth to bedrock, a shallow seasonal water table, or > 35% clay textures) or a limited suitable disposal area available on the property.

A rural property being considered for development with limiting soils that are not suitable for a conventional wastewater system are allowed to utilize an advanced treatment unit to manage the wastewater output. Advanced treatment units generate secondary-treated effluent which allows for being dispersed to a drip disposal area utilizing the soil for final renovation or an advanced treatment unit with an overland-flow discharge. Drip disposal may be considered in limiting soils, if the soils meet the minimum suitability requirements defined in the Arkansas Drip Rules and Regulations. The drip disposal tubing must be installed at a depth with at least 23 cm separation from bedrock and may not be installed in any seasonal water table noted (ASBH, 2010). An advantage of drip disposal is it can be utilized in limiting soils where a conventional wastewater system cannot. Disadvantages to utilizing drip disposal include the requirements of an additional license to design and an additional license to install, unique equipment to properly install the drip disposal tubing and additional infrastructure (control panel, headworks box, etc.) to manage the automatic or continuous flushing of the drip disposal tubing. When the soils are too limiting for an advanced treatment with drip disposal, an overland flow surface discharge is another option to manage the wastewater. However, an advanced treatment unit with an overland flow surface discharge requires at least 1.2 ha, minimum overland-flow setbacks from boundaries and neighboring homes and a National Pollutant Discharge Elimination System (NPDES) permit issued by the Arkansas Department of Environmental Quality (ADEQ). The investment in minimum land to meet overland-flow setbacks, the administrative requirements to maintain an NPDES permit and the environmental concerns associated with overland-flow discharging may place a burden on the homeowner. Limiting soils considered for development that cannot utilize an advanced treatment unit with drip disposal due to limitations of the soil, or cannot utilize an advanced treatment unit with an overland flow surface discharge point due to minimum land requirements are left with no other options to consider when developing a rural property.

Currently, there are no data to provide guidance for using the soil to renovate secondary-treated effluent in Arkansas. Arkansas has no loading rates defined for secondary-treated effluent. Tyler (2001) defined secondary-treated effluent loading rates based on organic loading of < 30 mg L^{-1} of BOD. Wastewater with low BOD levels was hypothesized to reduce pore clogging at the trench-soil interface. With the reduced bio-mat formation, soils could be hydraulically loaded with secondary-treated effluent at a rate greater than primary-treated effluent. Therefore, the focus of this study was to investigate the impact of hydraulically loading secondary-treated effluent into soils that are noted as too limiting for a conventional wastewater system or an advanced treatment unit with drip disposal. This study also considered soils that are not limiting, but have a reduced disposal area. Exploring an alternative method for managing secondary-treated effluent disposal may reduce the need for an overland flow NPDES permits, safely disperse secondary-treated effluent back into the hydrologic cycle, and provide development options as homeowners continue to move into rural areas that require an onsite wastewater system. It was hypothesized that limiting soils hydraulically loaded at two times the loading rate defined by Tyler (2001) with secondary-treated effluent will not exceed a ponding depth of 27 cm for a consecutive period greater than 14 days in any disposal trench. It was also hypothesized that the performance of a reduced shallow disposal field will differ over time, specifically between wet and dry seasons.

Materials and Methods

Site Description

Six individual homeowners were selected in 2016 within a 64-ha area of a single sub-division in Saline County, Arkansas (Figure 1). The homeowners' lots ranged in size from 1.2 to 4.8-ha, between three and four bedrooms, and had between two and six occupants throughout the duration of this study.

The study area, and six homes within the study area, resides in the thermic soil temperature regime within the Ouachita Mountains, Major Land Resource Area (MLRA) 119 (USDA, 1981). The mean annual air temperature in the region is 17ºC, while the mean annual precipitation ranges between 122 and 140 cm (McNab and Avers, 1994). Within the research sites, the soils are typically shallow to weathered shale and have argillic soil horizons that begin between 30 and 36 cm from the surface, where both shallow bedrock and argillic horizon presence can restrict water flow through the soil profile.

For four of the six sites, the soils are mapped as a Carnasaw-Townley association (fine, mixed, semiactive, thermic, Typic Hapludults) with no mounds present (Figure 2). Based on visual assessment, the soils present at these four sites had shallow seasonal water tables, as evidenced by redoximorphic depletions present to the soil surface. At the remaining two sites, the soils are mapped as a Caddo-Messer complex (fine-silty, siliceous, semi-active, thermic, Typic Glossaqualfs) with mounds present (Figure 2). Based on visual observation, the soils between the mounds had shallow seasonal water tables, as evidenced by redoximorphic depletions present to the soil surface, while the soils associated within the mounds had seasonal water tables evident by redoximorphic features beginning at approximately the 55-cm depth from the soil surface. However, based on the estimated volume of household wastewater produced at the two mounded sites, the amount of disposal area required by current Arkansas Rules and Regulations (ASBH, 2014), and based on redoximorphic features present, the area associated with the mounds was inadequate for a conventional disposal area. Therefore, all six sites had limiting soils due to shallow water tables (four sites) and/or had insufficient area of suitable soil (two sites) for a conventional wastewater system. As an alternative to the conventional wastewater system (i.e., septic tank, distribution box, and a disposal field), the Rules and Regulations for onsite wastewater disposal in Arkansas (ASBH, 2014) allow sites with limiting soils or disposal areas to utilize an advanced treatment unit to renovate household wastewater before discharging to an overland-flow point on the soil surface.

All six research sites utilized an advanced treatment unit manufactured by Orenco Systems (Model AX20-RT mode 1B, Sutherlin, OR) or Bio-Microbics, Inc. (Model MicoFAST 0.5, Lenexa, KS). Both types of units consisted of a settling compartment, a secondary-treatment compartment, and final compartment for ultraviolet (UV) disinfection and sampling. The advanced treatment units produce a quality of wastewater that is acceptable to discharge onto the soil surface, which is effluent containing 10 mg L^{-1} or less biochemical oxygen demand (BOD), 15 mg L^{-1} or less total suspended solids (TSS), 6 mg L^{-1} or greater dissolved oxygen (DO), and a pH between 6.0 and 9.0 (ADEQ, 2014). Consequently, each landowner in this study has a NPDES permit to surface-discharge their household wastewater after passing through the advanced treatment unit. Homeowners agreed to allow an experimental shallow-drain-field system to be installed on their property and to be studied to potentially find an alternative disposal method to surface discharging.

Treatments and Experimental Design

Among the six sites, two sites had experimental shallow-drain-field systems installed into the mounds that were present, while the other four sites, which had no mounds, had experimental shallow-drain-field systems installed on contour of the natural slope. Secondary-treated effluent loading rates were derived based on the soil texture at the most-limiting layer with guidance from previous loading rates derived for secondary-treated effluent (OWRD, 2002). The initial loading rates for the non-mounded (12.2 L m^{-2} d^{-1}) and mounded sites (32.5 L m^{-2} d^{-1}) were doubled for the non-mounded disposal sites (24.4 L m^{-2} d^{-1}) and doubled for the mounded sites (65.0 L m^{-2} d^{-1}). The six sites had similar site characteristics, including similar soil map units, soil profile textures, slopes, landscape positions, and other soil morphological characteristics (Table 1).

Site Evaluation and Disposal Site Construction

The initial three-month phase of this research project (September 2016 to December 2016) consisted of determining appropriate disposal areas, classifying the soils to be studied, and installing the new shallow-disposal areas at each site. Since each research area was to exist on an individual's property, careful consideration was given to the homeowner preference to locate each disposal area in an agreeable location for the study. Once an acceptable disposal area location was determined, one soil pit per site was excavated to an approximate depth of 120 cm in each of the defined disposal areas to evaluate the soil profile characteristics and establish a hydraulic loading rate. Soil descriptions were prepared for each horizon to a depth of 120 cm, recording information such as the texture by manual feel, estimated coarse fragment concentration (estimated to be 40%) in the upper 30 cm, moist matrix color, and redoximorphic feature (i.e., concentrations and depletions) presence and abundance. Representative soil samples were collected from each horizon for soil particle-size analyses using a modified 12-hr hydrometer method (Gee and Or, 2002) after oven drying for 48 hours at 70ºC and grinding and sieving sub-samples through a 2-mm screen.

Four disposal trenches were excavated at each site with a rubber-tracked 4500 kg track hoe. Disposal trenches were prepared 21-m long, 35-cm deep, 45-cm wide, and 1.2 m apart from each other, center to center (Figure 3). Disposal trenches were installed following the contour (i.e., the same elevation on the trench bottom along the length of a trench). Disposal trenches were backfilled with a 20-cm thick bed of commercially available washed crushed gravel, 2.5 cm in diameter or less (Figure 4). A low-pressure distribution network was constructed from 1.9-cm-diameter polyvinyl chloride (PVC), Schedule-40 pipe and installed in the center of each disposal trench atop the crushed-gravel bed (Figure 5). Holes, 0.32 cm in diameter, were drilled every 120 cm and protective orifice shields (STF-106TDS, SIM/TECH, Boyne City, MI) were snapped over each hole. Geotextile fabric (2624RB 24 x 300, Advanced Drainage Systems, Hilliard, OH) was cut to a 45-cm width and laid over the low-pressure distribution network and gravel bed. The gravel and pipes were then covered with 15 cm of native soil, with slight mounding over the disposal trench to allow for settling over time (Figure 6).

A 1.6-cm x 1.9-cm flow meter (MMPD Oscillating piston meter, Master Meter, Mansfield, TX) was installed at the supply line entering the upper-most disposal trench to measure flows (Figure 7). Polyvinyl chloride socket-gate valves, 2.67-cm diameter, were installed at the in-flow end of each lateral line for squirt height adjustment (Figure 8), where squirt height is a common visual assessment conducted to verify equal distribution in the low-pressure network of pipes because pressures can vary along lateral lines in the network due to position on the landscape. The gate valves allowed for adjustments to be made to make flows equal among each disposal trench. The gate valves were enclosed in a water meter box for easy access and adjustment when necessary. Polyvinyl chloride electrical flush sweeps, 2.67 cm in diameter with 2.67-cm-diameter female adapters and threaded plugs, were installed at the end of each lateral line for maintenance and to facilitate visual assessment of squirt heights (Figure 9). The flush sweeps were also installed in a water meter box for access.

In-trench monitoring ports, consisting of 8.9-cm diameter PVC pipe, were installed vertically in the middle of each disposal trench. Four slits, approximately 0.3-cm wide and 20-cm long, were cut vertically from the bottom up. The slits allowed for the soil solution to equilibrate inside the monitoring port so the depth from the soil surface to free solution (i.e., solution ponding) inside the trench could be measured (Figure 10).

An observation port, also consisting of 8.9-cm-diameter PVC pipe, was installed vertically to a depth of 60 cm approximately 1.5 m up-slope from the disposal area to allow for observation and measurement of the seasonal water table (Figure 11). Four slits, approximately 0.3-cm wide and 20-cm long, were cut vertically from the bottom up. The slits allowed free water to flow into the observation port to facilitate measurement of the depth to free water from the soil surface. When construction of each site was complete, the surface was manually seeded with a rye (*Lolium* spp.)-Bermudagrass (*Cynodon dactylon*) mixture at an approximate rate of 180-kg seed ha^{-1} and the seeded area was covered with straw to prevent erosion.

Each research site was connected to the homeowner's advanced treatment unit. Soil texture, determined during initial assessment of the disposal area, was used to set an expected effluent loading rate. The flow coming into the disposal site was recorded by reading the flow meter between observations and minor changes were made in the first month of the study by diverting excess flows or by turning off disposal trenches due to inadequate flows. Once the target effluent loading rate was achieved, no adjustments were made for the remainder of the study.

Effluent Source and Characterization

The secondary-treated effluent used to hydraulically load the shallow-disposal area came directly from the homeowners' advanced treatment unit via a pump and supply line. The overland-flow discharge point was re-rerouted to the study disposal area. A single-stage effluent pump or a turbine pump was used to supply effluent to the shallow drain fields. A control panel capable of time-dosing the secondary-treated effluent in small amounts throughout the day was used. Thus, each research site had secondary-treated effluent delivered in small, timed doses (Table 2), evenly distributed to the disposal site by the low-pressure distribution network.

Requiring the limiting soil profile to accept and transport primary-treated effluent may have complicated the study by the formation of a biomat or possible surfacing during the study causing an environmental concern. For this reason, the secondary-treated effluent was sampled and characterized every six months. Four grab samples were collected between September 2016 and September 2018 by a Class II wastewater operator and processed by a third-party laboratory (Environmental Services, West Markham, Little Rock, AR) for effluent characteristics, namely BOD, TSS, DO, and pH.

Disposal Site Monitoring

Monitoring of the disposal areas consisted of recording flows into each disposal area, the depth to free solution in each disposal trench, the depth to free water in the observation well, overall site conditions, and rainfall amounts. Disposal-site monitoring occurred at 14-day intervals over the 14-month research period (i.e., January 2017 to March 2018). Flows at each disposal site were recorded at the flow meter. The reading was recorded in written format and a digital picture was taken. Flows were compared against public water bill usage, which confirmed measured flows to each disposal site were reasonable. A hand-held tape measure was used to record ponding depths in the disposal trenches. Measurements were made from the downslope lip of the in-trench monitoring port to the top of the ponded-solution surface, if present. A tape measure was also used to record the depth to free water in the observation ports. Measurements were made from the downslope lip of the top of the observation port to top of the free-water surface, if present. During each site visit, signs of disposal-site stress, unique vegetation, and any other unique observations were also noted.

Rainfall was measured at Site A using a rain collection gauge made by Davis Instruments (model Vantage Vue, Davis Instruments, Hayward, CA) from September 2016 through January 2017. Rainfall data recorded at Site A was compared to rainfall data recorded within the research area that was publicly available through the Farm Logs web application (Farm Logs, 2018a). The Farm Logs rainfall history and tracking came from a dataset that the National Oceanic and Atmospheric Administration (NOAA) produced. The NOAA sources data from multiple radar and ground stations to algorithmically calculate the amount of precipitation that falls on a high-resolution grid across the continental United States. The NOAA factors in variables like wind and terrain that influence where the rain actually hits the ground, which was done within 1 km (0.6 mi) of accuracy (Farm Logs, 2018b). Rainfall amounts reported through the Farm Logs application were determined to be accurate when compared to the actual on-site measurements. Farm Logs rainfall data were used for the remainder of the study period after January 2017.

On January 1, 2018, an electronic monitoring device (SepticSitter™, Dynamic Monitors, Stratford, PE) was added to research Site A. The monitoring device recorded the depth to free water in the observation port and the depths to free solution in the in-trench monitoring ports with sonar. Measurements were recorded every 10 minutes for a 90-day period between January 1 and April 1, 2018. The ponding-depth data were transmitted at regular intervals throughout the day with a cellular connection and stored in the cloud for download. The monitoring equipment highlighted ponding-depth fluctuations, impact from rainfall on disposal site A, and provided near-real-time data to make observations.

Disposal Site Failure Criteria

Disposal site failure criteria have previously been based on the presence of a certain amount of solution storage in a trench for an extended period of time (Lowe and Siegrist, 2008; Lowe et al., 2006), as the disposal field trench is designed to facilitate dispersal of effluent into the soil rather than for storage. Based on guidance from several previous reports (Lowe and Siegrist, 2008; Lowe et al., 2006; Gibbons et al., 2015), for the purposes of this study, if any disposal trench in a disposal area had a solution ponding depth in excess of 27 cm, which was 8 cm from the soil surface, for two or more consecutive 14-day measurement intervals, the disposal trench was noted as an exceedance.

Data Analyses

In-trench and observation well ponding depths were plotted over time. Temporal trends in in-trench ponding depths among active, effluent receiving lines at each site were visually assessed relative to the soil surface, depth of the gravel, and depth of the bottom of the trench and for the frequency of in-trench ponding exceeding the depth to the in-trench gravel. Temporal trends of ponding depths in the observation wells were also visually assessed. In addition to visually assessing temporal trends in ponding depths, analysis of variance was conducted separately by site, using all temporal measurements as replications, using Minitab (version 13.31, Minitab, Inc., State College, PA) to evaluate differences in mean ponding depths over time among trench lines. Similar to Prater et al. (2013) and Gibbons et al. (2015), linear regression analyses were also conducted using Minitab, separately by trench line, to formally evaluate the temporal trend in ponding depths over time (i.e., whether ponding depths were increasing, decreasing, or not changing over time), as an increasing trend in mean ponding depth over time would indicate improper and undesired on-site system behavior. Significance was judged at $P < 0.05$ for all analyses (Table 3 and 4).

Results and Discussion

Effluent Characteristics

A prerequisite to studying a reduced drainfield in a limiting soil profile was to utilize secondary-treated effluent capable of meeting minimum overland-flow discharge requirements as defined by the Arkansas Department of Environmental Quality (ADEQ, 2014). The basic premise of using secondary-treated effluent in the study was to minimize the formation of a biomat by managing effluent with low BOD and TSS and large enough DO and, if surface ponding occurred, the environmental impact would be negligible (Table 5). Samples collected among the research site from April 2017 through April 2018 had a mean of 5.3 mg L^{-1} BOD, 8.5 mg L^{-1} TSS, 6.3 mg L^{-1} DO, and 7.4 pH. Consequently, the secondary-treatment water quality met or exceeded minimum secondary-treated surface discharge standards (ADEQ, 2014).

Rainfall Characteristics

Rainfall during the study period had a direct impact on the performance of the reduced drainfield in limiting soils (Figure 12). Rainfall measurements from March through July 2017 and December 2017 through March 2018 indicated 38% more rainfall than the 30-year normal. However, rainfall from August through November 2017 indicated 53% less rainfall than the 30-year normal. Data collected during the above-average rainfall periods provided information on how a reduced drainfield in limiting soils would react during hydrologically stressed conditions, as well as how the reduced drainfield would react during below-average rainfall conditions.

Non-mounded Sites

Seasonal Water Table Impact on Ponding Depths

Soil characteristics in the four non-mounded sites demonstrated the presence of a shallow seasonal water table. The A horizon, with a 10YR 2/2 matrix color, and the E horizon, with a 10YR 3/3 matrix color, provided evidence the seasonal water table rise and fall had caused reduction in the soil profile at the same proposed depth as the disposal trenches being studied. However, exactly how the fluctuating seasonal water table impacted the ability of the disposal area to accept daily doses of secondary-treated effluent was unknown.

Among the four non-mounded sites, the seasonal water tables depths, as measured in the observation ports up-slope of the upper-most disposal trench, ranged from 25 to > 80 cm from the surface (Figure 13). For the wet period of March through July 2017, the seasonal water table was recorded between 25 and 80 cm from the surface at Site A, D, E, and F compared to ponding depths in the disposal trenches, as measured by the monitoring ports within the disposal trenches themselves, recorded between 0 and 39 cm from the surface (Figure 14 through 17). For the dry period of August through November 2017, the seasonal water table was recorded at 65 to > 80 cm from the surface at Sites A, D, E, and F compared to the ponding depths in the disposal trenches of 8 to > 39 cm from the surface (Figure 18 through 21).

Measurements of the seasonal water table depths correlated with rain events and impacted ponding depths in the disposal trenches (Figure 21). Rain events and corresponding seasonal water table fluctuations accounted for 19 exceedances of a total of 116 observations (16%) between April 2017 and April 2018. An interceptor drain installed up-slope from the disposal area could be used to divert the seasonally shallow water table and may have alleviated a portion of the hydrologic stress to the disposal area at each site.

Peak Flows

Each non-mounded disposal site studied had existing infrastructure in place that included a 946-L dose chamber. The size of the dose chamber was adequate for dosing secondary-treated effluent to an overland-flow point. However, dosing secondary-treated effluent to a reduced disposal area would have benefited from having a larger dose tank. A larger dose tank would have allowed for improved equalization during peak-flow events. Site F changed ownership in December 2017 and one of the exceedances recorded was due to peak flows caused by excess laundry cycles on the move-in weekend. A larger dose chamber to store and equalize the flow throughout the day could have prevented the exceedance.

Size of Disposal Areas

The non-mounded disposal areas that received secondary-treated effluent covered 78 m^2, where each site had four lines that were 21.3-m long on 1.2-m centers. The redoximorphic features of the soil in the non-mounded sites had no corresponding loading rate in the Arkansas Rules and Regulations (ASBH, 2014) to compare a similar disposal area using primary-treated effluent. However, if a loading rate of 8.4 L m^{-2} d^{-1} (Tyler, 2001) was assumed based on the soil texture of the most-limiting horizon (i.e., a clay-textured horizon at some relatively shallow depth at all sites), and a standard trench spacing of 2.4-m was used, the disposal area required would have been 372-m^2 using primary-treated effluent. Utilizing secondary-treated effluent in a reduced disposal area that occupied only 21% of the area required for primary-treated effluent was a significant area reduction when contemplating an alternative method to disposing of secondary-treated effluent other than by overland-flow surface discharging or when the suitable area for disposal is greatly limited.

Hydraulic Loading

The accepted flow for a three-bedroom home per the Arkansas Rules and Regulations is 1400 L d^{-1} (ASBH, 2014). The four non-mounded sites had average daily flows > 454 to < 1749 L d^{-1} (Table 6). The objective of the study was to load each disposal site at a minimum of two times the loading defined by Tyler (2001) for secondary-treated effluent. Flows were recorded and adjustments were made from January through February 2017 to meet the minimum objective. Site A had excess flow due to additional infiltration and inflow of climatic water. Site D measured minimal flows from the home and did not have an exceedance or ponding depth to record in any trench, except for one occurrence on December 23, 2017 when a ponding depth was measured after a 7.6-cm rain the night before. However, the ponded water was no longer evident in the disposal trench three days later. Site E and F had expected flows for a three-bedroom home of 697 to 768 L d^{-1}. The four non-mounded sites achieved > 2, but < 3.8 times the accepted loading rate for secondary-treated effluent (Table 6).

Lateral Movement

Due to the 2 to 4% slope of the disposal areas at all four research sites, sub-surface lateral movement of secondary-treated effluent between trenches was expected and evolved over the study period. From January through February 2017, the ponding depths from line 1 (i.e., the most up-slope line) through line 4 (i.e., the most downslope line) remained relatively uniform with similar ponding depths in each disposal trench in three of the four sites. However, beginning in March 2017 through the remainder of the study, the ponding depths among trenches developed dissimilarities. Line 1 typically had the lowest or non-existent ponding depth and lines 2, 3, and 4 would all show incrementally greater ponding depths the further downslope. The disposal area was receiving secondary-treated effluent through the low-pressure distribution laterals equally over the entire disposal area; however, after the first 30 days, the secondary-treated effluent followed a tortuous path from trench line 1 to the downslope disposal trenches.

Based on all temporal measurements, ponding depths differed ($P < 0.03$) among lines at sites A, E, and F, but was unaffected by trench line at site D, where mean ponding depth averaged 0.9 cm across all four lines throughout the entire study (Table 3). At site A, mean in-trench ponding depth increased by a factor of 1.8 from lines 1 and 2, which did not differ, to lines 3 and 4, which did not differ. At sites E and F, mean ponding depth increased 6- and nearly 2-fold, respectively, from line 1 to lines 2 and 3, which did not differ. Understanding the lateral, sub-surface flow phenomenon may allow a designer to hydraulically load the upslope-most disposal trench with more secondary-treated effluent and, by the same logic, hydraulically load the more downslope trenches with less secondary-treated effluent and expect effluent renovation from sub-surface, lateral movement of effluent between trenches.

Among the four non-mounded sites, none of the four lines at any site had ponding depths that changed over time throughout the duration of the study, except for line 4 at site F, which significantly decreased over time (Table 4). These results indicate that, at least within the first 18 months after initial dosing, the secondary-treated effluent was of sufficient quality to minimize biomat formation which is often cited as the reason for absorption field failure when using primary-treated effluent.

Wet Spring and Dry Fall Impacts on Disposal Sites

Shallow seasonal water tables noted in the non-mounded disposal sites A, D, E and F showed redoximorphic indicators in the upper 30 cm of soil. Seasonal water table fluctuations between March and July 2017 directly impacted ponding depths (Figure 14 through 16). Measuring ponding depths in disposal trenches stressed by shallow seasonal water table fluctuations provided insight into how limiting soil profiles, due to a shallow seasonal water table and during stressed conditions, may still provide an acceptable method for disposal and renovation of secondary-treated effluent. During the dry period from August through December 2017, the limited or absence of a seasonal water table provided insight into how limiting soil profiles performed without the influence of seasonal water table fluctuations (Figure 17 through 19). Comparing the average ponding depth of the most hydraulically loaded disposal trench (lowest) during March through July 2017 to the average ponding depth of the same disposal trench from August through December 2017, there was a 38% reduction in the ponding depth during the dry period. Managing the shallow seasonal water table in a limiting soil profile and its impact on a disposal area was not part of this study; however, the observation could be made that, if a soil profile was limiting due to shallow seasonal water table and the seasonal water table was diverted around the disposal area using an interceptor drain, the efficiency of the disposal area in the disposal area would improve.

Ponding Depths for Site A vs. Site D

Sites A and D were located on the same landscape position (backslope), had the same slope (3%), and similar soil profile characteristics, with the minor exception of the depth to the textural change (Table 1). Site A had a textural change from extremely gravely loam to clay at a depth of 30 cm, while Site D had a textural change from extremely gravely loam to clay at a depth of 40 cm. This small difference resulted in Site A having a measurable ponding depth in one or all of the disposal trenches throughout the study, where Site D did not have measurable ponding in any of the disposal trenches throughout the study, with exception of after a single rain event in December 2017. The secondary-treated effluent being evenly dispersed over the disposal area in small doses throughout the day was able to percolate through the profile at Site D due to the 10-cm zone of extremely gravely loam and move laterally downslope. The secondary-treated effluent at Site A ponded at the textural transition to clay at the 30-cm depth. Based on the data collected, textural changes in the profile should be taken into consideration when contemplating disposal of secondary-treated effluent in a reduced disposal area in profile-limiting soils, which should apply to any disposal site, regardless of using primary or secondary-treated effluent.

Visual Changes in Vegetation

Landscape vegetation within the disposal areas and downslope from the disposal areas was notable. Sites A and F were affected downslope the greatest with changes in vegetation and a noticeable plume of nutrient-rich deposition, likely phosphorus and nitrogen-rich solution, as a result of the up-slope disposal area (Figure 23). Sites D and E had no noticeable change within or downslope from the disposal area (Figure 24). Observing the changes in vegetation throughout the study highlighted where the secondary-treated effluent was traveling laterally and downslope. The sites with noticeable changes in vegetation were also the sites that had exceedances. Sites D and E had no noticeable changes in vegetation and less exceedances. Vegetation on or downslope from a disposal area can be an indicator of the efficiency or stress experienced in a disposal area.

Ponding Depths in Line 4 When Line 4 was Turned Off

During the initial measurement period from September 2016 to February 2017, the number of disposal trenches utilized during the study was adjusted to reflect a loading rate at a minimum of two times the accepted loading rate for secondary-treated effluent. Each disposal site was tied to a homeowners’ water usage habits and being able to turn off a disposal trench (i.e., allow no effluent to be delivered to a trench) to achieve the focus of the study was necessary. Site A had disposal lines 1 through 4 utilized during the entire study. Sites E and F had three of the four disposal lines utilized during the study (i.e., lines 1, 2, and 3). Site D used only one of the four disposal lines during the study (i.e., line 1). Although Sites D, E, and F had at least one disposal line turned off, ponding depths were still recorded for each of the four-disposal lines. Site A always had a measurable ponding depth in the lower disposal trench

(Figure 26). Sites E (Figure 27) and F (Figure 28) had measurable ponding depths in line 4. Site D did not have any measurable ponding to record for the duration of the study, with exception of after a single rain event in December 2017 (Figure 29). Observing the ponding depths in the lower disposal lines, when secondary-treated effluent was not delivered to the lowest disposal line, clearly demonstrated the sub-surface, lateral movement of the secondary-treated effluent downslope. Based on the data, the concept of sub-surface, lateral flow should be considered in the design criteria when using a reduced disposal area and secondary-treated effluent in profile-limiting soils, as sub-surface, lateral movement of effluent would still provide renovation despite the effluent's minimal vertical flow in the soil profile.

Continuous-ponding-depth Measurements

Site A was retrofitted with data collection equipment that allowed for ponding depths in each disposal trench and the observation well to be measured and recorded continuously at 10-minute intervals. Data were collected from February through March 2018. The ability to record and observe the ponding depths in the disposal trenches and the rise and fall of the seasonal water table within short time intervals provided greater insight into the behavior of the effluent and the seasonal water table than did manual measurements at 14-day intervals. The seasonal water table rise and movement through the disposal trenches at the 30-cm depth, where the textural discontinuity occurred, confirmed what was previously measured. Ponding depths of secondary-treated effluent corresponded with hourly doses from the treatment system, as well as the effect from the rise of the seasonal water table after a rain event (Figure 30). The data gathered during the 31-day continuous measurement period were useful in illustrating seasonal water table and secondary-treated-effluent interactions at a finer temporal resolution and confirmed other manual measurements made at 14-day intervals. If resources allow, it may be useful to outfit troublesome sites with continuous monitoring equipment to better understand the dynamic interactions between secondary-treated effluent and climatic water at short time intervals.

Mounded Sites

Seasonal Water Table Impacts on Ponding Depths

Soil characteristics in the mounded sites showed suitable soils for primary-treated effluent disposal, but with limited disposal area. The A and E horizons, which occupied the top 40 cm, were loam textured with a 10YR 4/3 matrix color and showed no redoximorphic features. The B horizon was a loam in the 40- to 120-cm depth with a matrix color of 10YR 5/4 with depletions of 10YR 7/2 color and concentrations of 10YR 3/6 color noted from in the 55- to 120-cm depth interval. The redoximorphic features noted at the 55 cm depth were well-below the disposal trench depth of 35 cm. Observation well ponding depth measurements recorded at sites B and C from March 2017 through March 2018 showed no seasonal water table. Based on the data collected, the seasonal water table was not a limiting factor for secondary-treated effluent disposal at sites B or C.

Peak Flows

Each mounded disposal site studied had existing infrastructure in place that included a 946-L dose chamber. The size of the dose chamber was adequate for dosing secondary-treated effluent to an overland-flow point. However, similar to the non-mounded sites, dosing secondary-treated effluent to a reduced disposal area would have benefited from having a larger dose tank. A larger dose tank would have allowed for improved equalization during peak-flow events. However, peak flows throughout the study did not show evidence of an exceedance in ponding depth in either of the mounded sites B or C.

Size of Disposal Areas

The mounded disposal areas that received secondary-treated effluent covered 60 m^2. Each of the two sites had four lines, 12-, 15-, 18-, and 21-m long on 1.2-m centers (Figure 31). The depth to redoximorphic features of the soil in the mounded sites translated into a loading rate in the Arkansas Rules and Regulations (ASBH, 2014) of 30.5 L m^{-2} d^{-1} using a standard trench spacing of 2.4 m, thus the disposal area would have required 145 m^2 using primary-treated effluent. Utilizing secondary-treated effluent in a reduced disposal area required 41% the area required for primary-treated effluent. Similar to the non-mounded sites, the disposal-area reduction is significant when contemplating an alternative method to disposing of secondary-treated effluent other than by overland-flow surface discharging.

Hydraulic Loading

The two mounded sites had average daily flows that ranged from > 416 to < 1703 L d^{-1} (Table 3), whereas the accepted, estimated flow for a three-bedroom home is 1400 L d^{-1} (ASBH, 2014). Neither site B nor C had enough flow to measure an exceedance or ponding depth in any of the disposal lines throughout the entire study. The two mounded sites achieved > 2.5, but < 3.8 times the accepted loading rate for secondary-treated effluent (Table 4).

Wet Spring and Dry Fall Impacts on Disposal Sites

In contrast to the non-mounded sites, sites B and C had redoximorphic features below 55 cm. No appreciable ponding was documented at site B or C throughout the study. Thus, season, either wet or dry, did not affect the performance of the disposal trenches. The disposal trenches at sites B and C were installed at 36 cm, which was above the noted depth to redoximorphic features. Installing disposal trenches above a fluctuating, seasonal water table improves the ability of the trench to disperse and renovate the introduced wastewater.

Visual Changes in Vegetation

In contrast to the non-mounded sites, changes in landscape vegetation within the mounded disposal areas, or downslope from the mounded disposal areas, were negligible (Figure 32 and 33). Sites B and C did not show any changes in vegetation within or downslope of the disposal area, which corresponded with the lack of any ponding-depth exceedances recorded during the study.

Ponding Depths in Line 4 When Line 4 was Turned Off

Similar to the non-mounded sites, during the initial measurement period from September 2016 to February 2017, the number of disposal trenches utilized during the study were adjusted to reflect a loading rate at a minimum of two times the accepted loading rate for secondary-treated effluent. Sites B and C used only one of the four disposal lines during the study (i.e., line 1). Though site B had significantly greater mean ponding in line 4 than in the other three lines, the mean ponding depth was only 0.7 cm (Table 3). Similarly, ponding depth did not differ among lines at site C and averaged only 0.7 cm per line throughout the duration of the study

(Table 3). Thus, sites B and C did not have any appreciable effluent/water ponding for the duration of the study in any of the lower disposal trenches beyond line 1. Consequently, in contrast to the non-mounded sites, lateral movement of secondary-treated was not evident at sites B or C throughout the study.

Similar to most of the non-mounded sites, ponding depth in the lines at the two mounded sites did not change over time (Table 4). The lack of an increase in ponding depth over time lends credibility to the feasibility of using secondary-treated effluent in a shallow drainfield with reduced area.

Implications

If managed properly, secondary-treated effluent disposed in limiting soils or reduced disposal areas can be considered an alternative for disposal sites with limiting soils that previously were deemed unsuitable. Disposing of wastewater back into the soil profile versus an overland-flow discharge protects the environment by utilizing the soil as the final destination (i.e., hydrologic cycle), reduces the regulatory burden and compliance challenges with surface discharges, and is the responsible way to manage the wastewater.

Throughout the study, the impact from fluctuating seasonal water tables was a factor in the efficiency of the disposal areas. Further research is required to study the impact of an interceptor drain installed up-slope from the disposal sites in limiting soils to divert the brief seasonal water table around the disposal area to increase the efficiency and decrease the exceedances in the disposal area. An interceptor drain would pair well with what was learned during the study regarding site A's and D's ponding depths. Sites A and D both had limiting soils, the same slope, and the same textural properties. However, site D had the disposal trenches installed just above the textural change from loam to clay loam, where site A had the trenches installed in the clay loam. Site A had in-trench ponding throughout the study, where Site D had no ponding throughout the study. The implications of installing an interceptor drain and installing the trenches at a depth of 25 versus 35 cm at sites A, E, and F to remain above the textural change may have resulted in no to fewer exceedances during the study. In summary, understanding the soil profile and textural characteristics, the slope and surrounding landscape position of the disposal area, and understanding the lateral movement of water through the soil profiles suggests it is conceivable to utilize the soil as final disposal for secondary-treated effluent in soils similar to those studied versus a surface discharge.

Conclusions

Managing wastewater in rural settings is becoming a challenge as Arkansans' move into areas where conventional wastewater systems are not feasible. When considering an alternative to a conventional wastewater system, there are limited empirical data supporting disposing of secondary-treated effluent in limiting soils other than by overland-flow surface discharge. Results showed that soils that may be unsuitable for a conventional wastewater system may be suitable using secondary-treated effluent with a shallow or a reduced disposal area.

Based on the absence of appreciable secondary-treated effluent ponding at sites B, C, and D during the study and the minimal exceedances in site A, E, and F, which was linked directly to fluctuating seasonal water tables, it is reasonable to consider hydraulically loading secondary-treated effluent at a rate Tyler (2001) established based on soil textures and structure. Consideration must be given to hydraulically loading secondary-treated effluent in unsuitable soils or suitable soils with a reduced disposal area.

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Appendix

Table 1. Summary of soil and landscape characteristics and soil limitations for each of the six research sites.

Site	Map Unit	Texture	Slope (%)	Type	Slope Position	Limitation
A	Carnasaw[a], steep	SCL	3	Non-mounded	Backslope	Seasonal water table
B	Caddo, complex	L	5	Mound	Backslope	Disposal area
C	Caddo, complex	L	5	Mound	Backslope	Disposal area
D	Carnasaw[b], steep	SCL	3	Non-mounded	Backslope	Seasonal water table
E	Carnasaw undulating	SCL	2	Non-mounded	Backslope	Seasonal water table
F	Carnasaw, steep	SCL	4	Non-mounded	Backslope	Seasonal water table

[a] Fine, mixed, semi-active, thermic Typic Hapludults
[b] Fine-silty, siliceous, active, thermic Typic Glossaqualfs

Table 2. Summary of the dosing frequency used for disposal at research Sites A through F. Each of the sites listed have logic in the control panel to override time-dose settings in the event of a high-level event.

Site	Working Volume[a] (L)	Minimum Dose to Pressurize[b] (L)	Daily Flow Average[c] (L)	Pump Flow Rate[d] ($L\ min^{-1}$)	Timer On[e] (min)	Timer Off[f] (min)
A	132	32	1749	189	0.50	80
B	378	9.5	863	105	0.75	130
C	378	9.5	458	105	0.75	240
D	378	9.5	488	105	0.75	240
E	132	24	697	113	0.50	120
F	378	24	772	105	0.75	144

[a] Working volume is the amount of storage in the dose tank utilized to level the daily flow.
[b] Minimum dose to pressurize is the amount of secondary-treated effluent required to fill the lateral pressure distribution infrastructure.
[c] Daily flow average represents the average daily flow during the study period.
[d] Pump flow rate is the calculated flow of the effluent pump as it delivers secondary-treated effluent to the disposal area.
[e] Timer On is the setting in the control panel that tells the discharge pump to run for a specific period of time.
[f] Timer Off is the setting in the control panel that tells the discharge pump how long to rest.

Table 3. Summary of effect of disposal-area trench line on ponding depth over time by site.

		Mean Ponding Depth (cm)			
Site†	***P*-value**	**Line 1**	**Line 2**	**Line 3**	**Line 4**
A	0.03	5.4a	8.2a	11.5b	13.1b
B	0.01	0.0a	0.1a	0.1a	0.7b
C	0.33	0.2	0.7	1.3	-
D	0.99	0.6	0.9	0.9	1.1
E	0.01	0.9a	6.0b	5.1b	0.0a
F	< 0.01	13.9a	25.3b	25.9b	12.4a

† Sites A, D, E, and F were non-mounded sites and had effluent dosed to lines 1-4, 1, 1-3, and 1-3, respectively. Sites B and C were mounded and had effluent dosed to only line 1.

Table 4. Summary of linear regression analyses among all temporal measurements to assess whether ponding depths were increasing, decreasing, or not changing over time. Bolded values were considered significant at the 0.05 level. The arrows in parentheses indicate whether the ponding depth trend was increasing or decreasing.

Site	Line 1	Line 2	Line 3	Line 4	Observation Well
			P		
A	0.09	0.24	0.94	0.78	**0.04 (↑)**
B	-	0.17	0.17	0.10	-
C	0.96	0.19	0.15	-	-
D	0.58	0.58	0.58	0.58	0.13
E	0.78	0.83	0.39	0.53	0.07
F	0.20	0.14	0.15	**0.01 (↓)**	0.60

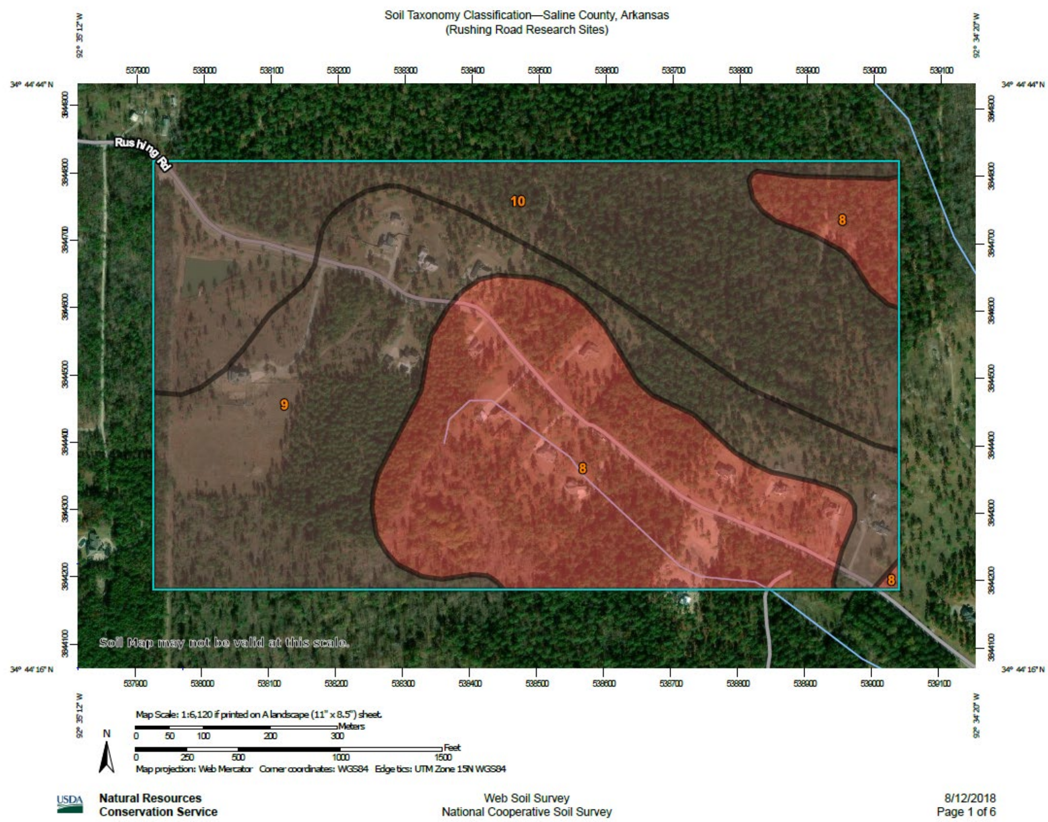
Table 5. Summary of effluent characteristics [i.e., total suspended solids (TSS), biological oxygen demand (BOD), and dissolved oxygen (DO)] over time among the six research sites and averaged across research sites.

Effluent Parameter	Sample Date	Site A	Site B	Site C	Site D	Site E	Site F	Average
TSS (mg L^{-1})	4/11/2017	8	7	11	19	5	19	11.5
	10/9/2017	1	2	22	6	1	19	8.5
	4/10/2018	4	2	1	7	6	6	4.3
BOD (mg L^{-1})	4/11/2017	15	2	4	2	2	2	4.5
	10/9/2017	7	3	24	5	4	2	7.5
	4/10/2018	2	2	6.7	3.8	3.4	7.3	4.2
DO (mg L^{-1})	4/11/2017	8.0	6.3	4.3	6.5	7.9	6.9	6.7
	10/9/2017	6.7	6.5	3.5	6.5	6.3	6.7	6.0
	4/10/2018	6.5	6.7	6.1	6.3	7.3	3.4	6.0
pH	4/11/2017	7.4	6.2	6.5	6.5	7.3	6.5	6.7
	10/9/2017	7.4	6.2	7.5	6.5	4.5	6.8	6.4
	4/10/2018	7.6	6.7	7.0	7.0	7.9	7.0	7.2

Table 6. Summary of average daily flow and loading rates among the six research sites. Flows were recorded at the flow meters entering the disposal site at 14-day intervals throughout the study. Average flows are reported. Flows were also compared to home water meter reading to verify accuracy.

Site	Flow ($L\ d^{-1}$)	Disposal area (m^2)	Design ($L\ m^2\ d^{-1}$)	Actual ($L\ m^2\ d^{-1}$)	Multiplier
A	1749	37.6	12.2	46.5	3.8
B	863	7.0	32.5	123.3	3.8
C	458	5.6	32.5	81.5	2.5
D	488	9.8	12.2	49.7	2.0
E	697	29.3	12.2	23.8	2.0
F	772	29.3	12.2	26.3	2.2

Figure 1. Aerial image of research Sites A through F in Saline County, Arkansas. Google Earth image created on 2/26/2019 (Google Earth, 2018).



Map Unit Symbol	Map Unit Name	Taxonomic Description	Area (ha)	Percentage of Area (%)
8	Caddo-Messer variants complex	Fine-silty, siliceous, Semiactive, thermic Typic Glossaqualfs	24	33.8
9	Carnasaw-Townley association, undulating	Fine, mixed, Semiactive, thermic Typic Hapludults	24	33.8
10	Carnasaw-Townley association, steep	Fine, mixed, Semiactive, thermic Typic Hapludults	23	32.4
Total for Area of Interest			71	100.0

Figure 2. Soils map and soil taxonomy classification for research area in Saline County, Arkansas (USDA-NRCS, 2018).

Figure 3. Disposal-area trench line 1 of 4 at research Site A that has been excavated and filled with gravel.

Figure 4. Image of the crushed 57 stone with granite lithology. The size of stone ranges from 1.3 to 3.8 cm. This crushed stone material is self-compacting and allows for the flow of water and air.

Figure 5. Image of the low-pressure distribution network installed at Site A to control and deliver secondary-treated effluent to the four disposal lines.

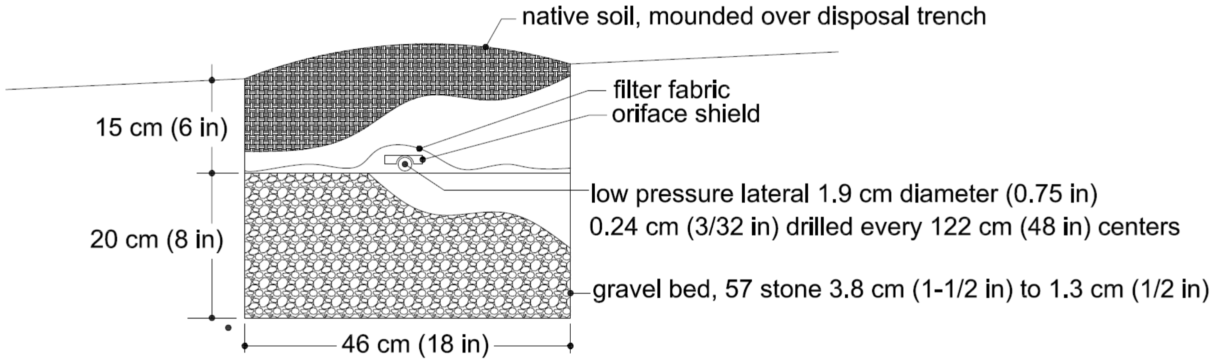


Figure 6. Side view of installed trench at each research site. Disposal trenches were installed following the surface contour.

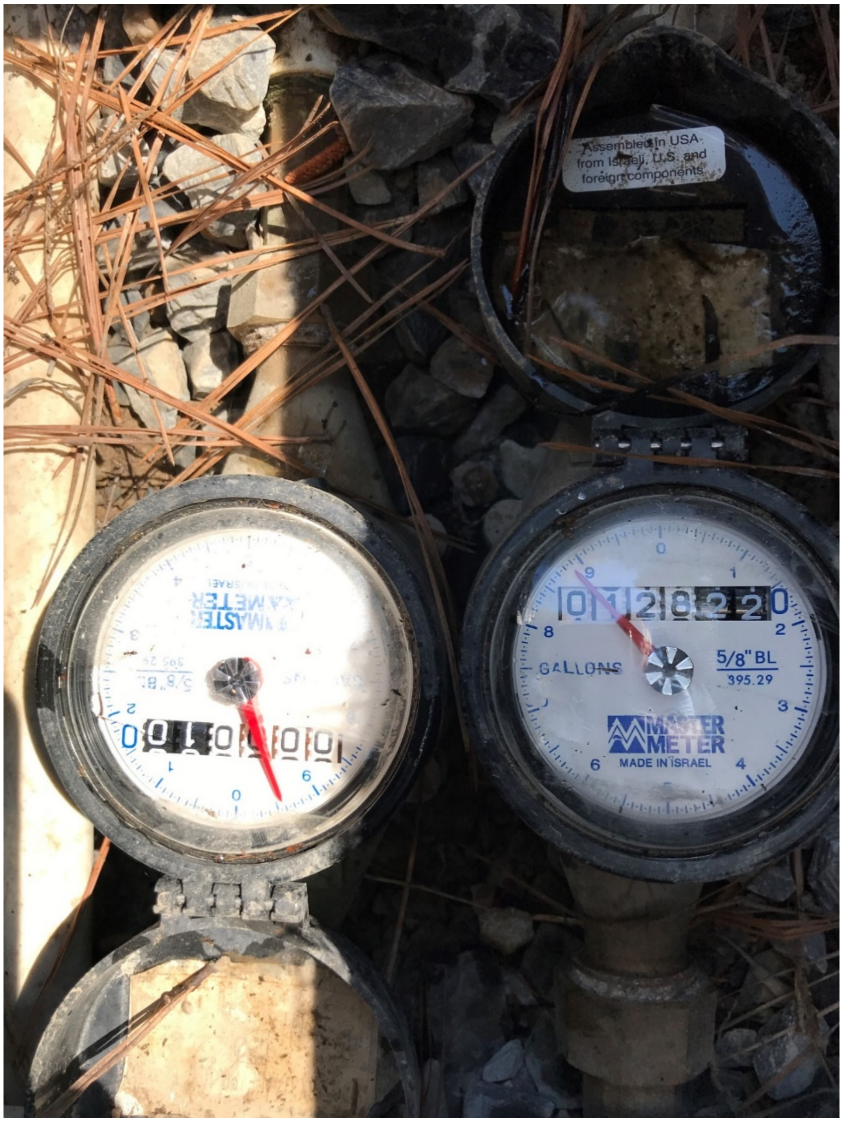


Figure 7. Image of flow meters installed at each research site
to record the flow of secondary-treated effluent into the disposal area.

Figure 8. Image of gate valves installed at site E. Gate valves were used to regulate squirt height across the disposal area for even distribution.

Figure 9. Image of the flush sweeps installed at site A. Flush sweeps allow for squirt-height measurement and the ability to flush the low-pressure distribution network.

Figure 10. Image of an in-trench monitoring port being installed at site B. Site B was one of the mound disposal areas. The inspection port is used to measure ponding depths within the disposal trench. Each trench has its own monitoring port.

Figure 11. Image of an observation port that was installed up-slope of the upper-most disposal trench at site A. The observation port was used to monitor and measure the depth of the seasonal water table.

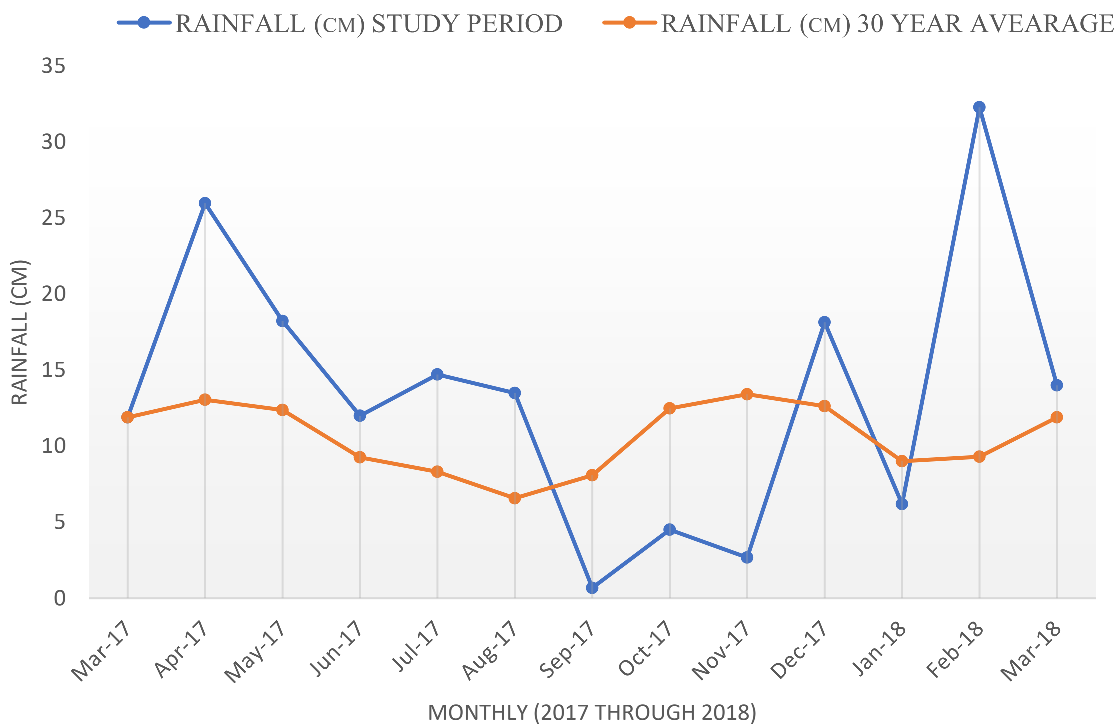


Figure 12. Monthly rainfall data, both actual and 30-year (1981-2010) average amounts associated within the study area.

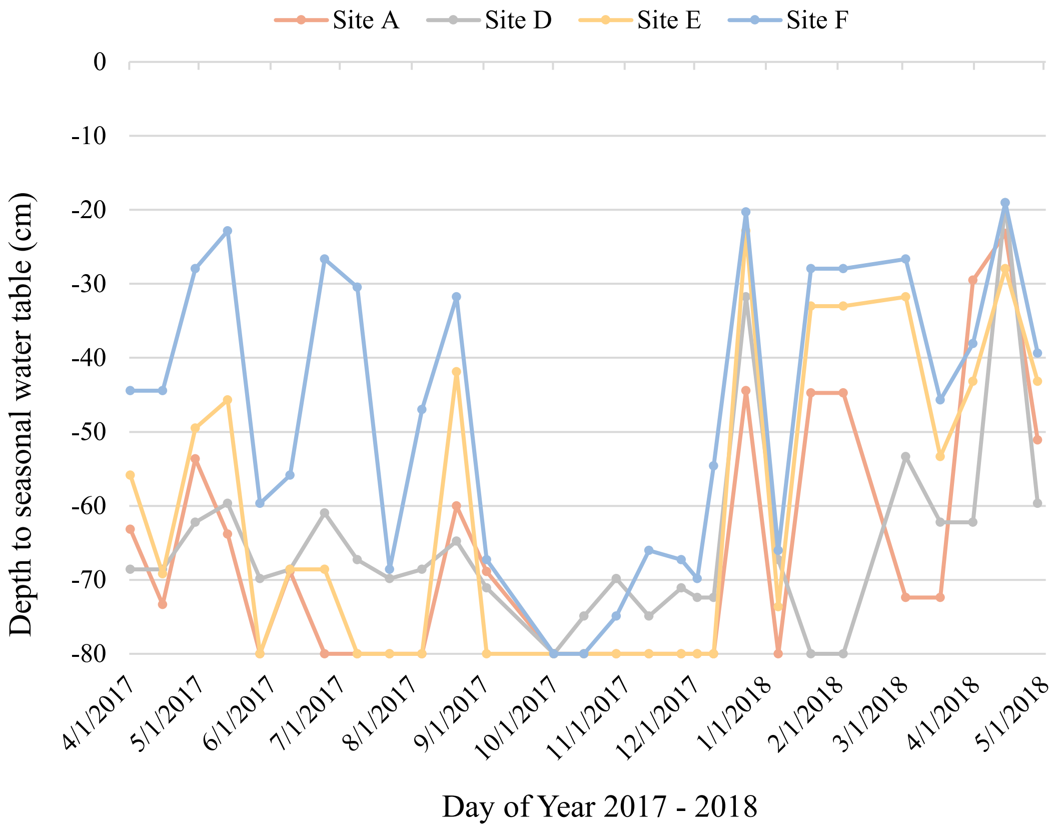


Figure 13. Seasonal water table fluctuations from April 2017 to May 2018 from the up-slope observation port at research sites A, D, E, and F. The soil surface is the 0-cm line on the y-axis. The bottom of the observation well is at the -80-cm line depth.

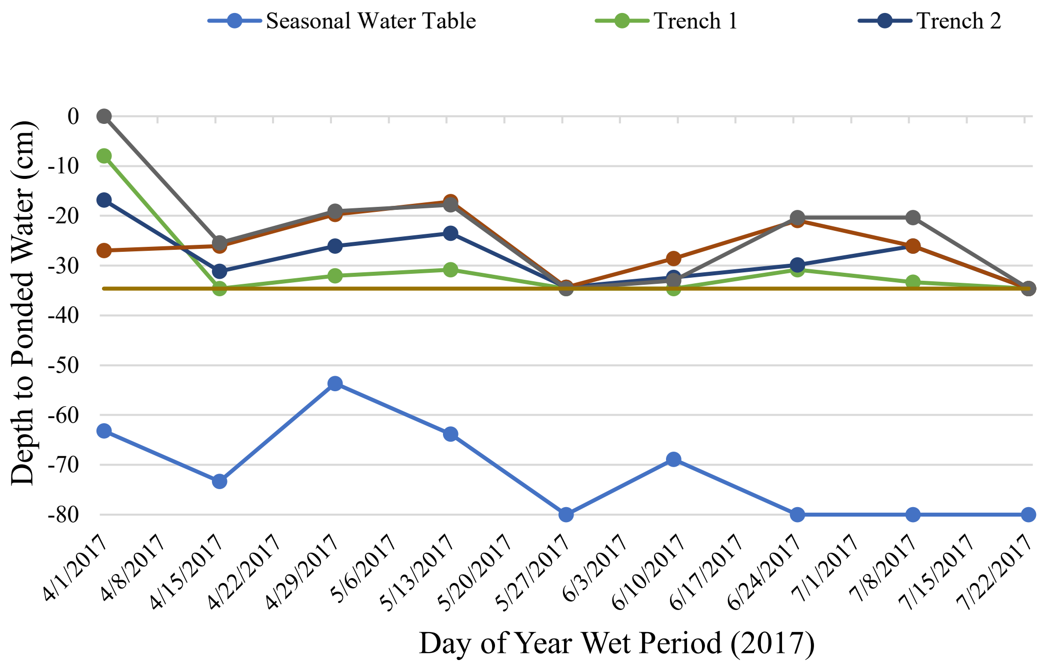


Figure 14. Depth to ponded secondary-treated effluent during the wet period of April to July 2017 from the up-slope observation port and the four disposal trenches at research Site A. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 35-cm depth mark.

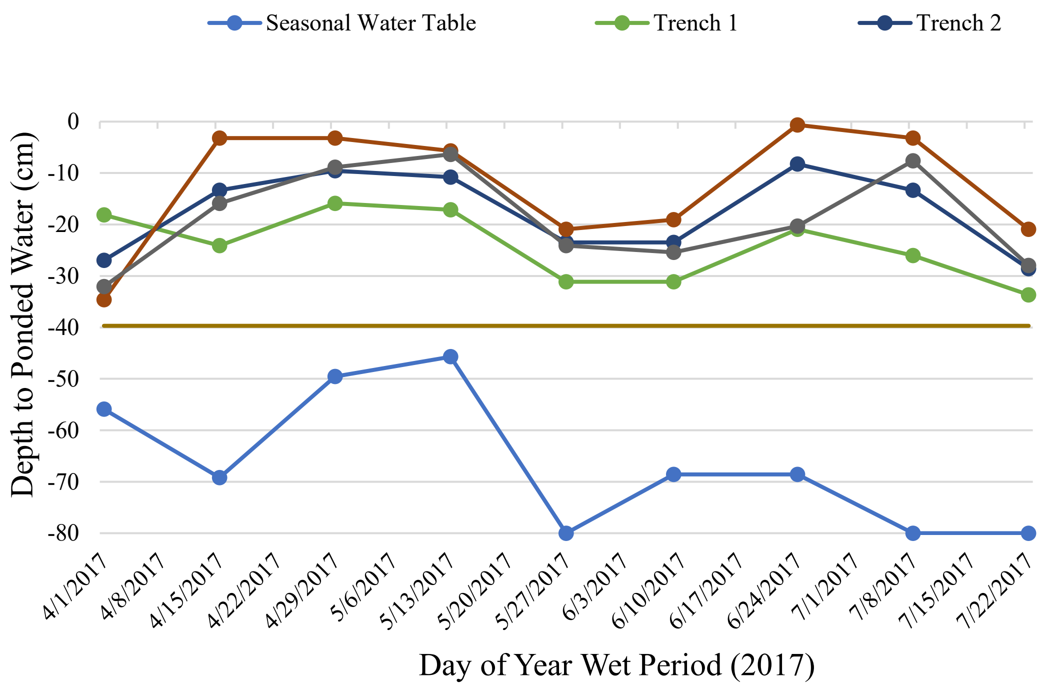


Figure 15. Depth to ponded secondary-treated effluent during the wet period from April to July 2017 from the up-slope observation port and the four disposal trenches at research Site E. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 40-cm depth mark.

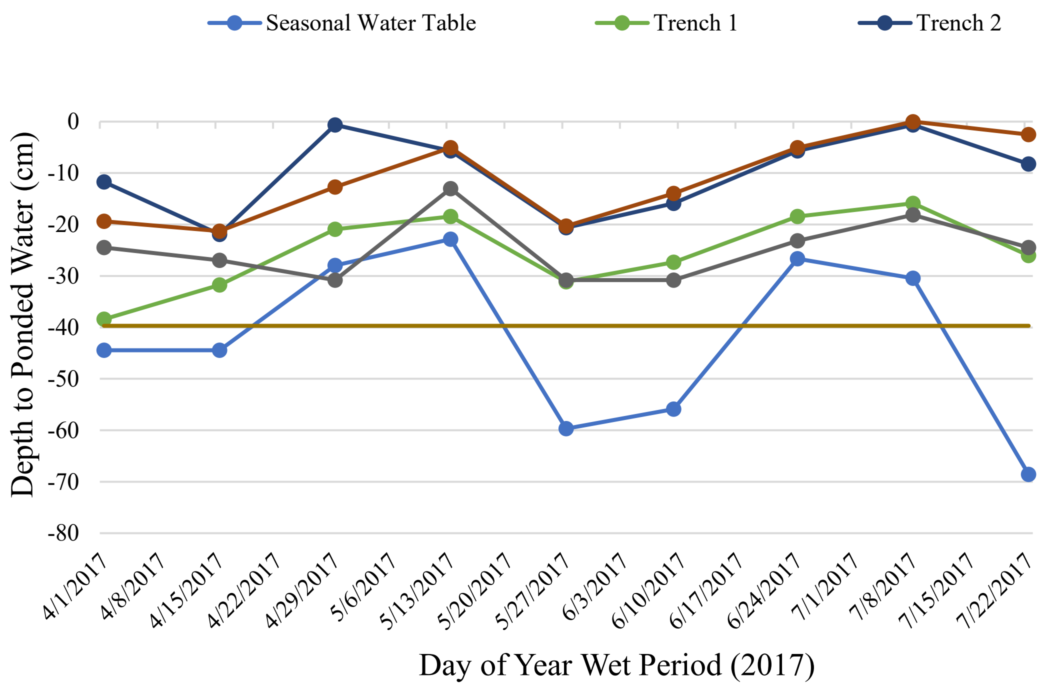


Figure 16. Depth to ponded secondary-treated effluent during the wet period from April to July 2017 from the up-slope observation port and the four disposal trenches at research Site F. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 40-cm depth mark.

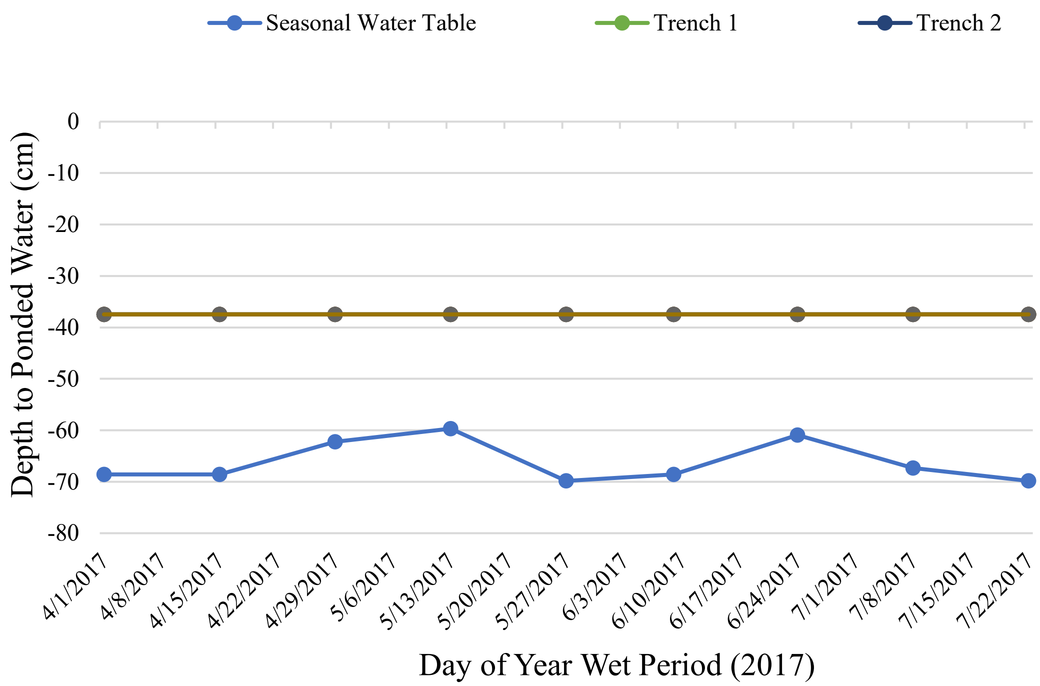


Figure 17. Depth to ponded secondary-treated effluent during the wet period from April to July 2017 from the up-slope observation port and the four disposal trenches at research Site D. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 37-cm depth mark. No ponding was measured during the study period. However, the seasonal water table was present throughout this period.

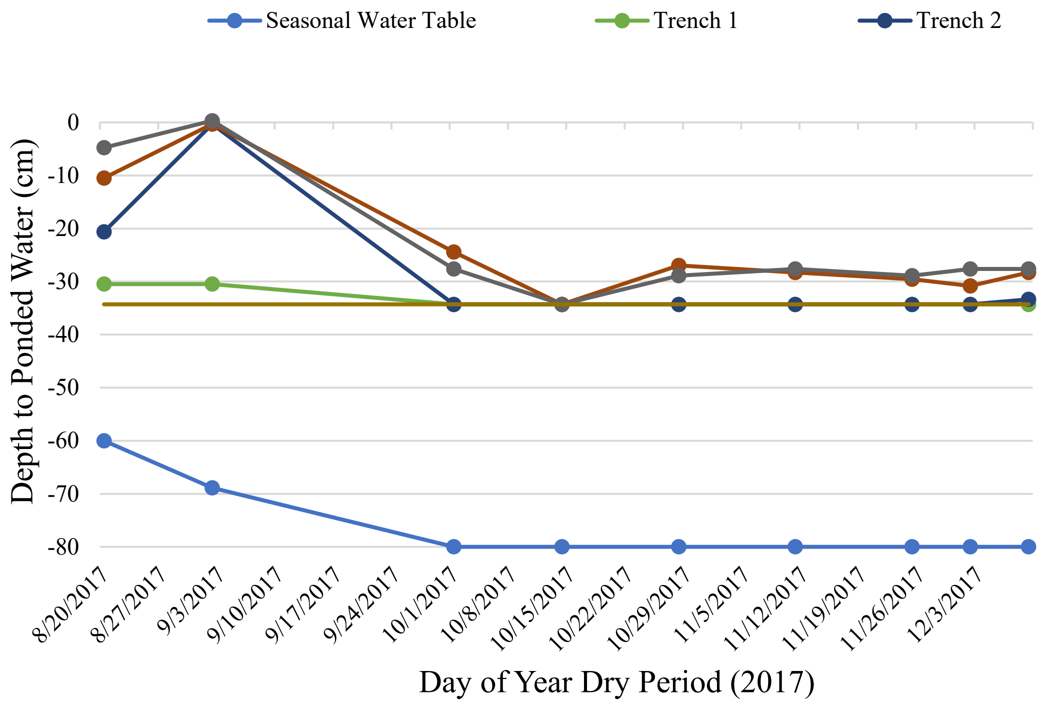


Figure 18. Depth to ponded secondary-treated effluent during the dry period from August to December 2017 from the up-slope observation port and the four disposal trenches at research Site A. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 34-cm depth mark.

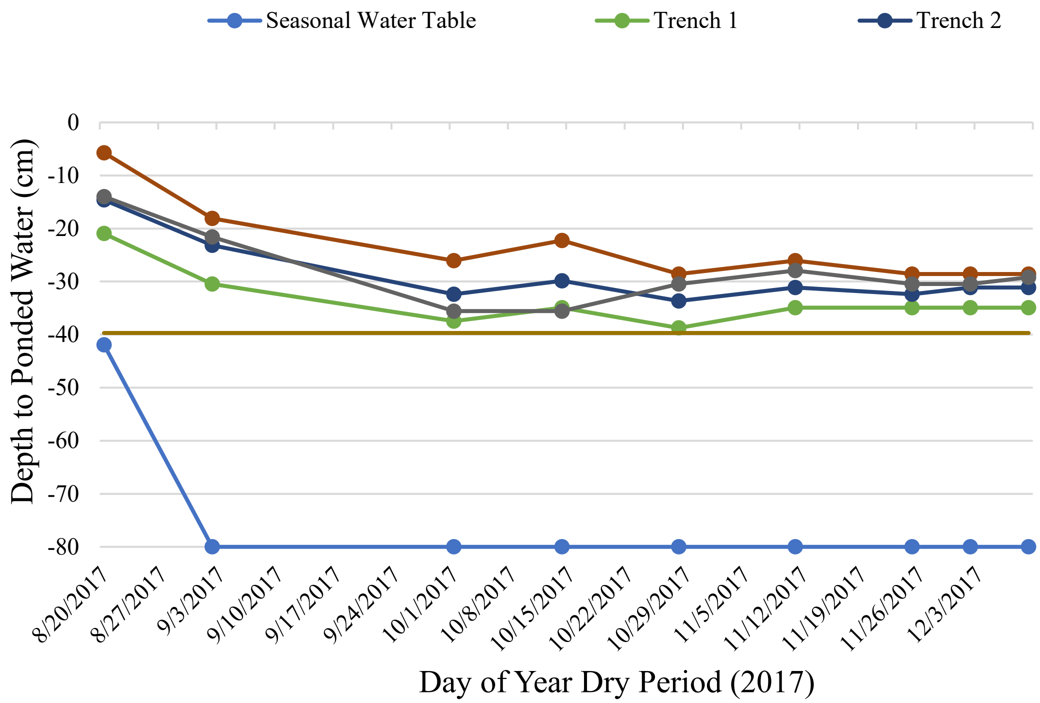


Figure 19. Depth to ponded secondary-treated effluent during the dry period from August to December 2017 from the up-slope observation port and the four disposal trenches at research Site E. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 40-cm depth mark.

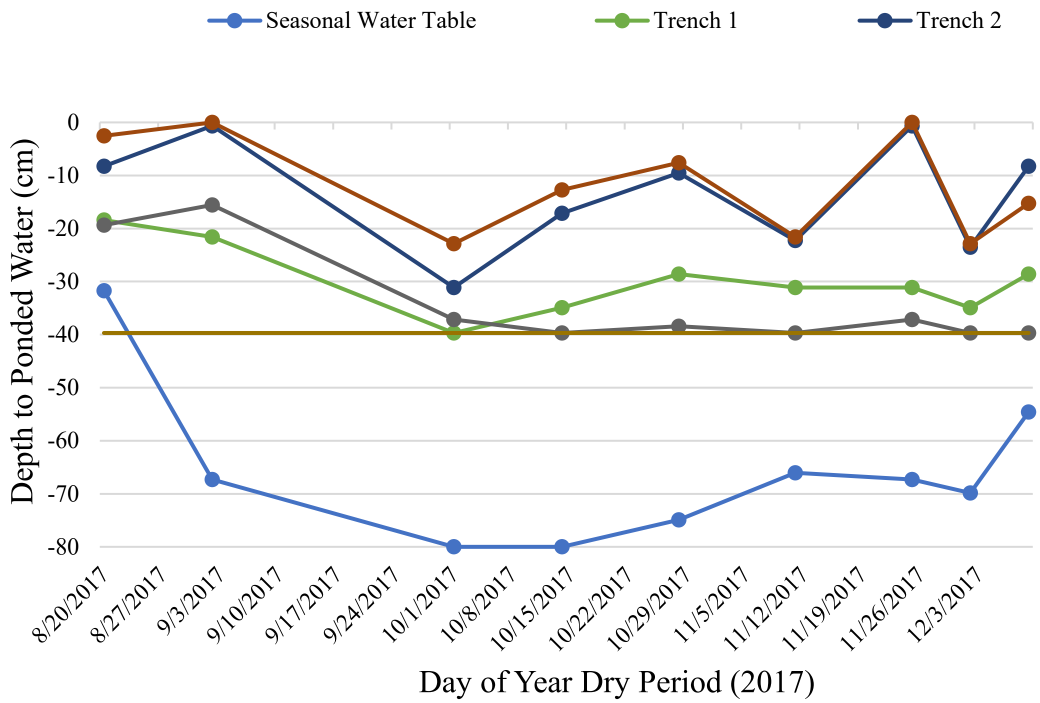


Figure 20. Depth to ponded secondary-treated effluent during the dry period from August to December 2017 from the up-slope observation port and the four disposal trenches at research Site F. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 40-cm depth mark.

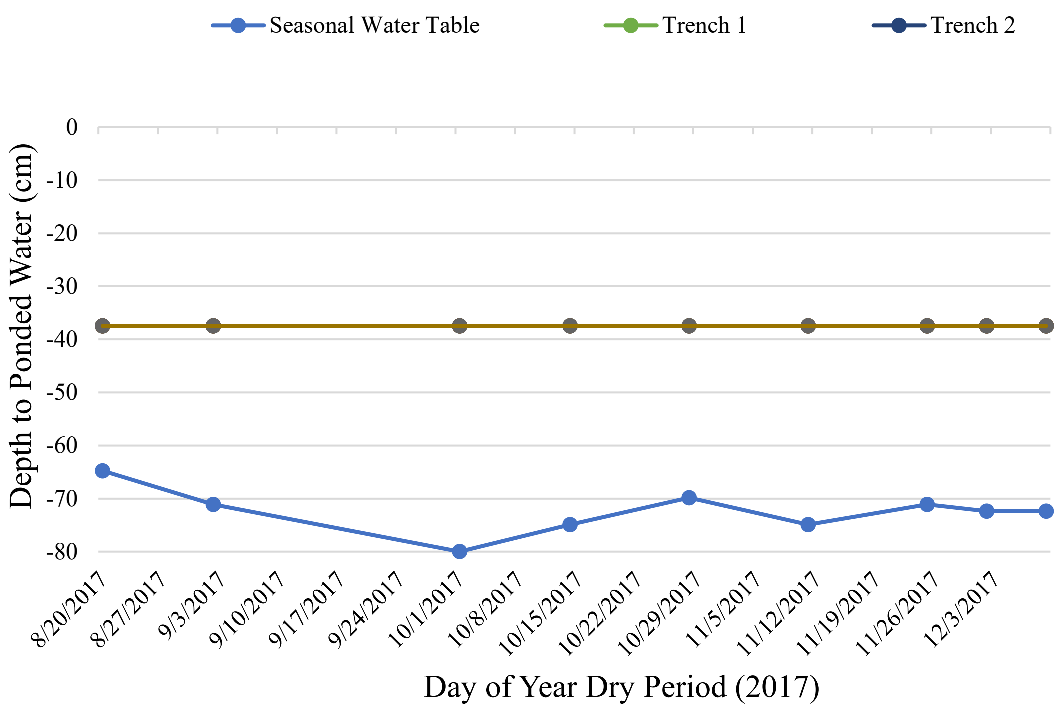


Figure 21. Depth to ponded secondary-treated effluent during the dry period from August to December 2017 from the up-slope observation port and the four disposal trenches at research Site D. The soil surface is the 0-cm mark on the y-axis. The trench bottom is at the 37-cm depth mark. No ponding was recorded in any trench during this period. However, the seasonal water table was present throughout the study period.

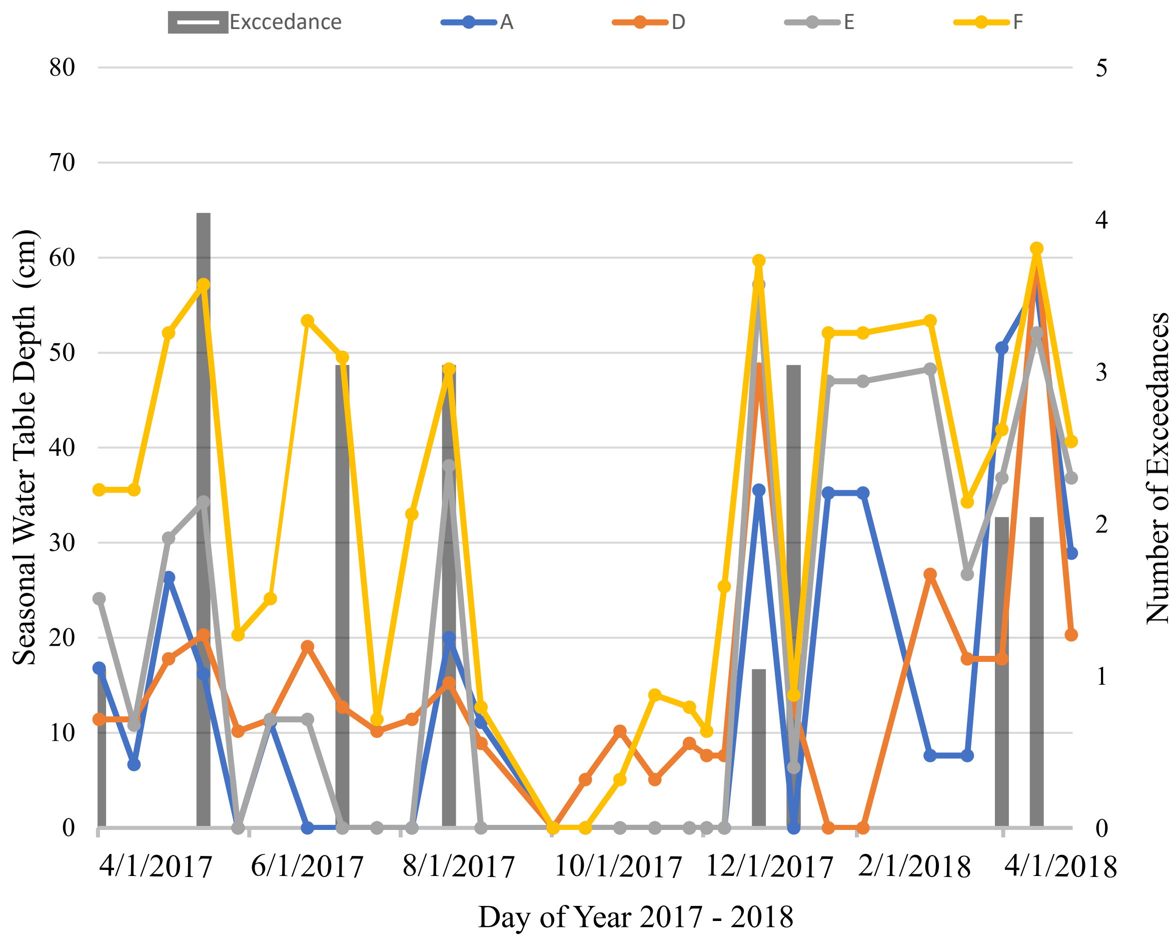


Figure 22. Seasonal water table fluctuations compared to exceedances. The surface is represented on the left y axis by 80 cm. The bottom of the observation port is represented on the left y axis by 0 cm. The number of exceedances is represented on the right y axis. The exceedances represent any monitored period > 14 days where any of the trenches in sites A, D, E or F had a ponding depth > 27 cm. Site B and C were not represented in this graph because no seasonal water table was measured, nor exceedance recorded during the study.

Site A

Site F

Figure 23. Vegetation on disposal sites A and F returned to native grass and showed signs of nutrient-rich plumes along the disposal trenches or down slope from the disposal areas.

Site E

Site D

Figure 24. Vegetation on disposal sites E and D returned to native grass and show little signs of nutrient-rich plumes or failure.

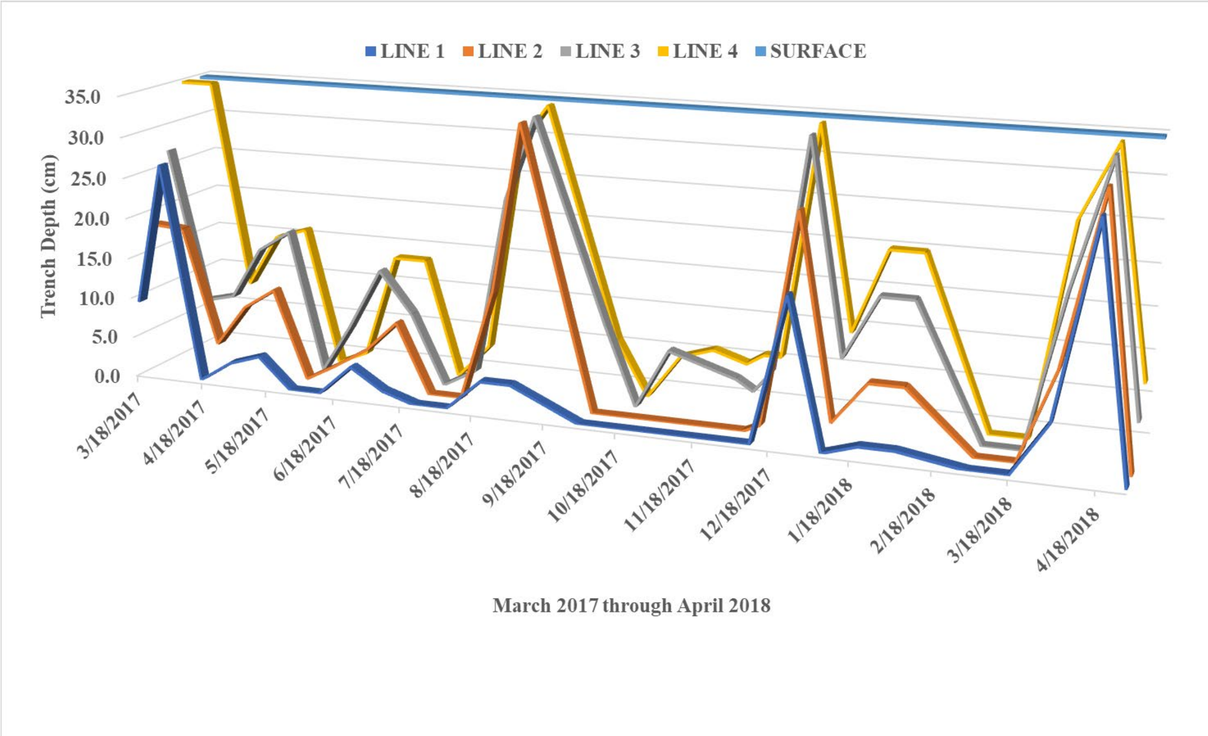


Figure 25. Lateral movement of secondary-treated effluent at site A. Observation dates are represented on the x axis. The y axis represents the depth of the disposal trench where 35 cm is the surface and 0 cm represent the bottom of the trench. Although the secondary-treated effluent is evenly distributed to four disposal trenches, ponding depths incrementally increased as the water moved laterally downslope.

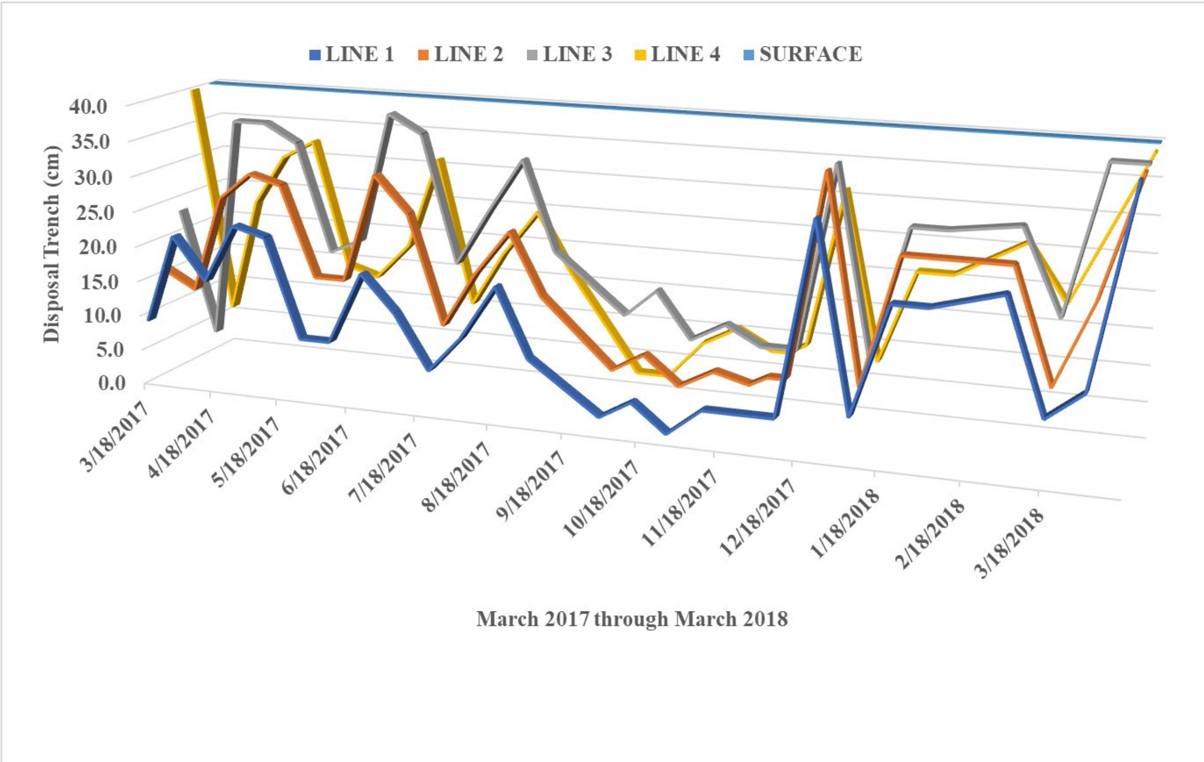


Figure 26. Lateral movement of secondary-treated effluent at site E. Observation dates are represented on the x axis. The y axis represents the depth of the disposal trench where 40 cm is the surface and 0 cm represent the bottom of the trench. Although the secondary-treated effluent is evenly distributed to three disposal trenches, ponding depths incrementally increased as the water moved laterally downslope. Line 4 in disposal site E was turned off in March 2017, however, a ponding depth was recorded throughout the study further highlighting the lateral movement of secondary-treated effluent in the disposal area.

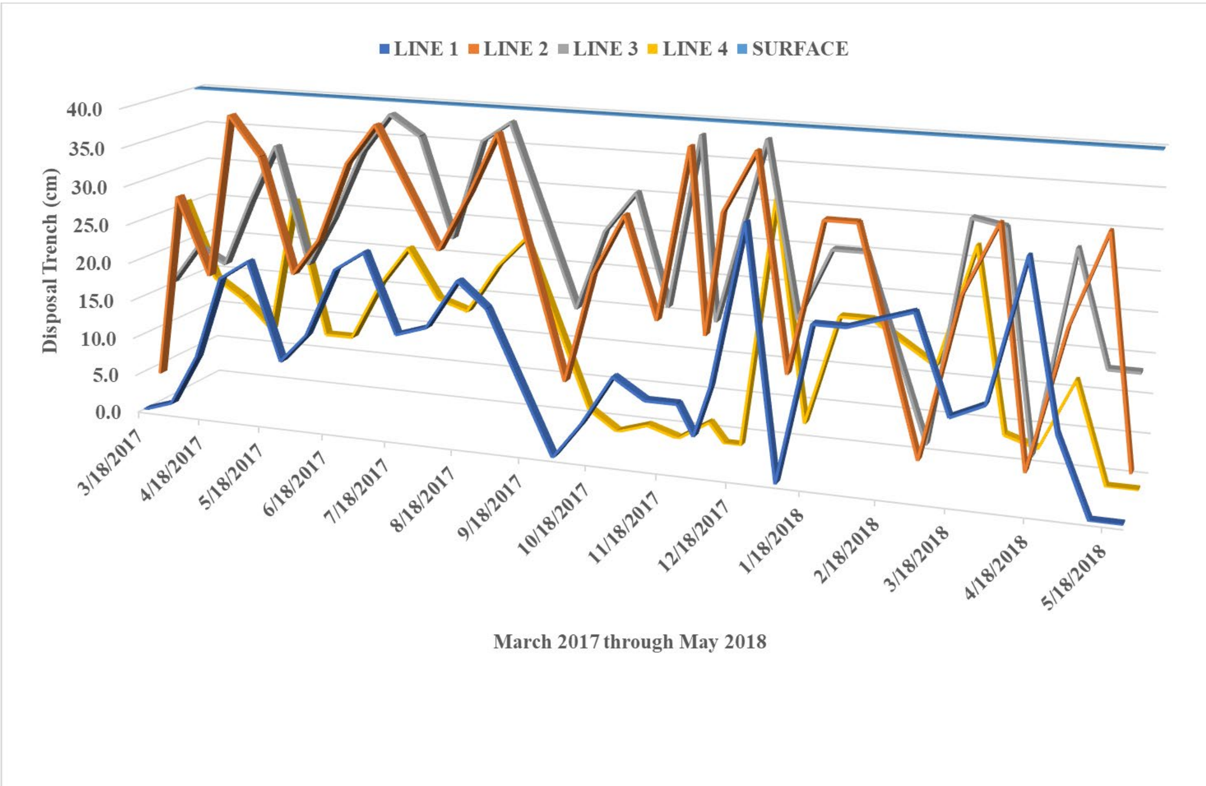


Figure 27. Lateral movement of secondary-treated effluent at site F. Observation dates are represented on the x axis. The y axis represents the depth of the disposal trench where 40 cm is the surface and 0 cm represent the bottom of the trench. Although the secondary-treated effluent is evenly distributed to three disposal trenches, ponding depths incrementally increased as the water moved laterally downslope. Line 4 in disposal site E was turned off in March 2017, however, a ponding depth was recorded throughout the study further highlighting the lateral movement of secondary-treated effluent in the disposal area.

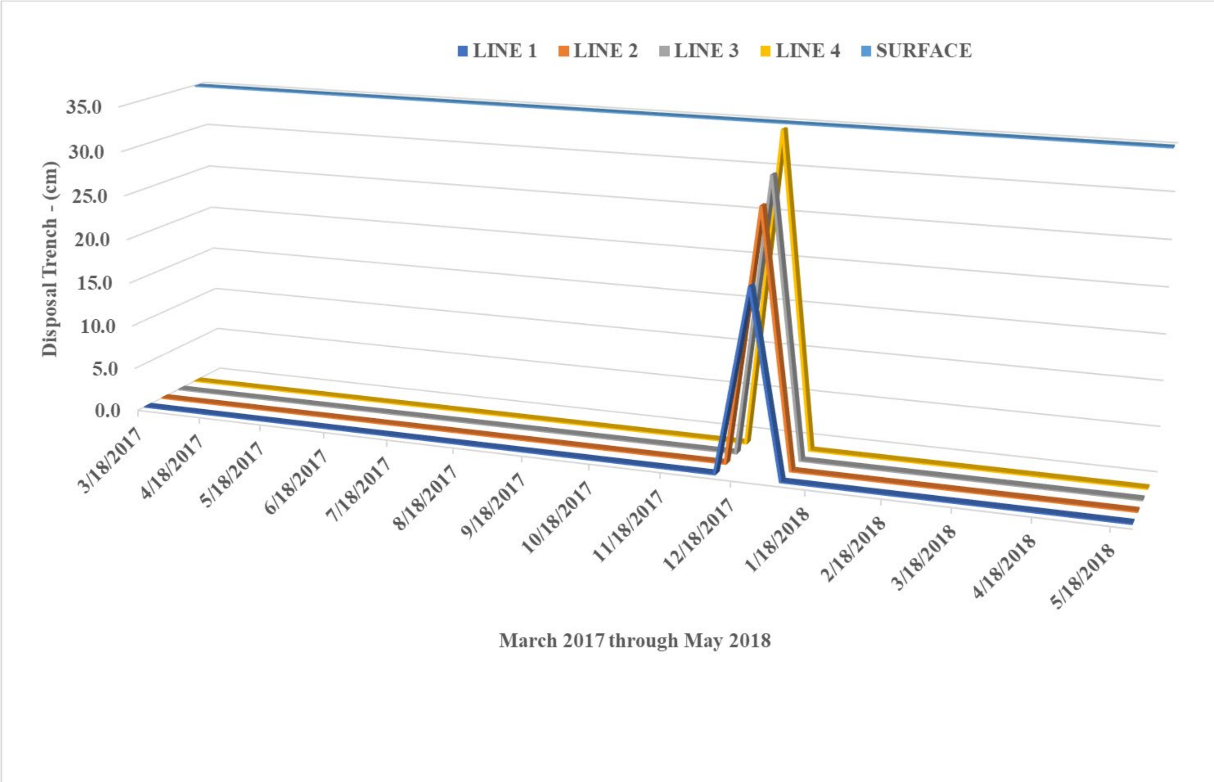


Figure 28. Ponding depths at site D were recorded in December 2018 after a heavy rain the night before, while 3 days later, ponding was non-measurable. Lines 2,3, and 4 were turned off in March 2017. Secondary-treated effluent ponding depth is represented on the y axis where the 35-cm mark represents the surface and the 0-cm mark represents the bottom of the disposal trench.

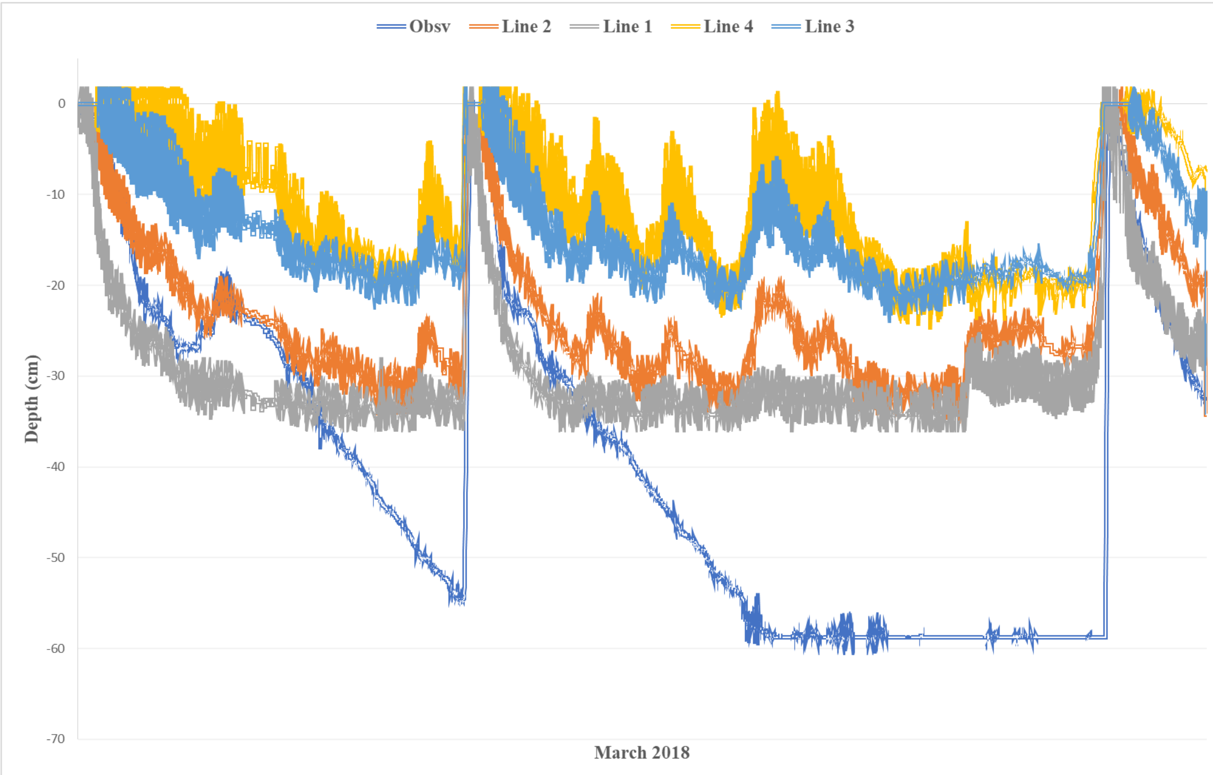


Figure 29. Forty thousand data points recorded by SepticSitter™ from March 1st through March 31st 2018. The vertical axis represents the depth of soil profile. The 0-cm mark equals the soil surface, the -35-cm mark represents the bottom of the disposal trenches, the -58-cm mark represents the bottom of the observation well. Three rain events occurred during the measurement period, one at the beginning of March, one in the middle, and one towards the end. Note how quickly a rain event impacted the disposal trench ponding depths and how quickly recovery occurred.

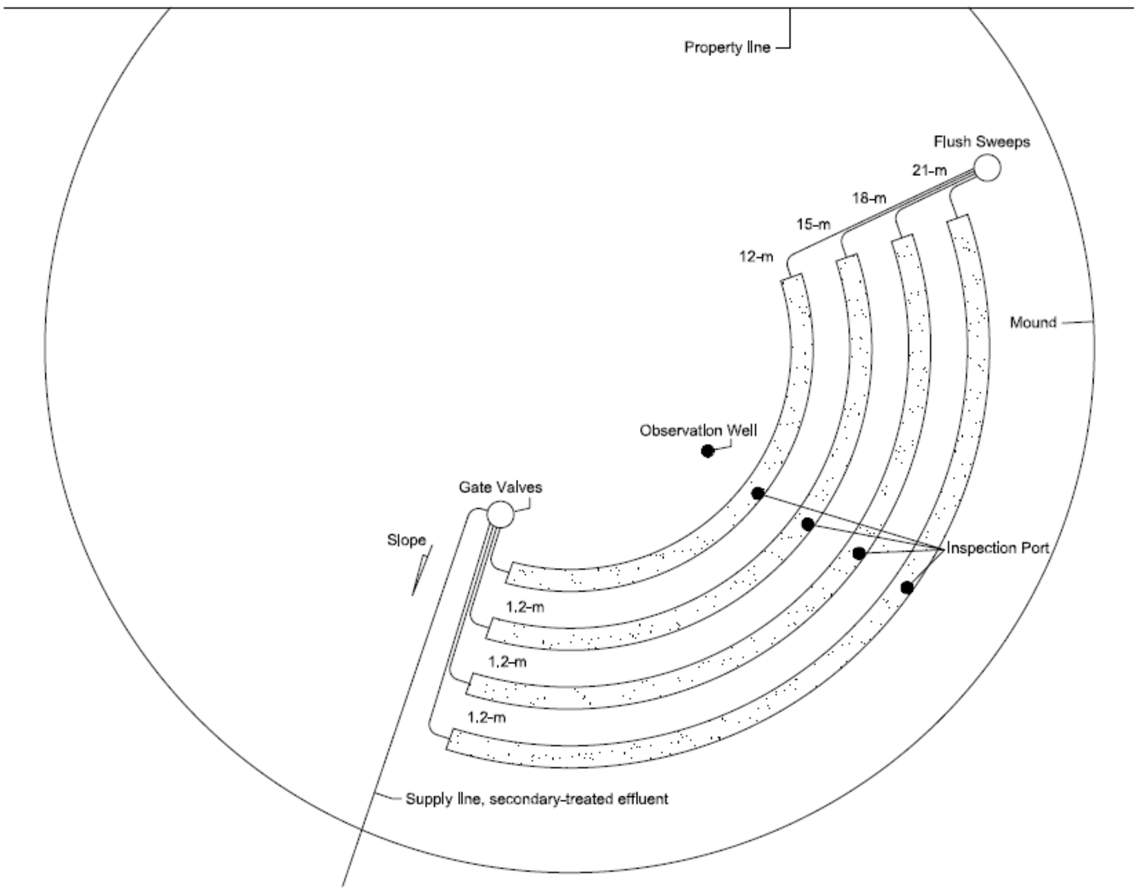


Figure 30. Top-view layout of site B. Site B has raised mounds throughout the property. The mound represents 131 m². The disposal area utilized 45% of the mound or 60 m².

Figure 31. Mounded disposal area of site B. Picture taken 4/28/18. Disposal area covers 60 m².

Figure 32. Mounded disposal area at site C. Picture taken 12/9/2017. Disposal area covers 60 m².

References

Google Earth V 7.3.2. (October 10, 2018). Rushing Road, Little Rock, Arkansas. Lat 34.741452 Lon -92.579881 Elv 572 ft. Google Earth Pro 2018. https://www.google.com/earth (verified March 9, 2019).

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Conclusions

Managing wastewater in rural settings is becoming a challenge as Arkansans' move into areas where conventional wastewater systems are not feasible. When considering an alternative to a conventional wastewater system, there are limited empirical data supporting disposing of secondary-treated effluent in limiting soils other than by overland-flow surface discharge. Results showed that soils that may be unsuitable for a conventional wastewater system may be suitable using secondary-treated effluent with a shallow or a reduced disposal area.

Based on the absence of appreciable secondary-treated effluent ponding at sites B, C, and D during the study and the minimal exceedances in site A, E, and F, which was linked directly to fluctuating seasonal water tables, it is reasonable to consider hydraulically loading secondary-treated effluent at a rate Tyler (2001) established based on soil textures and structure. Consideration must be given to hydraulically loading secondary-treated effluent in unsuitable soils or suitable soils with a reduced disposal area.